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THE

MINERALOGICAL MAGAZINE

AND

Journal of The Mineralogical Society.

INSTITUTED FEBRUARY 3, 1876.

EDITED BY L. J. SPENCER, M.A.

ASSISTED BY A COMMITTEE OF COUNCIL.

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1916.

MINERALOGICAL SOCIETY.

(*Instituted February* 3, 1876.)

BYE-LAWS.*

1. The object of the Mineralogical Society of Great Britain and Ireland, with which the Crystallological Society was amalgamated on December 11, 1883, shall be to advance the knowledge of Mineralogy, and also of Crystallography and Petrology.

2. The Society shall consist of Ordinary Members and Honorary Members.

Ordinary Members.

3. Every candidate for Ordinary Membership shall be proposed by two Ordinary Members, one, at least, of whom shall have personal knowledge of the candidate.

4. Elections to Ordinary Membership shall be made by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

5. Ordinary Members shall pay an entrance fee of one guinea and an annual subscription of one guinea. Ordinary Members elected on or before November 13, 1900, shall be entitled to compound for the annual subscription by a single payment of ten guineas: Ordinary Members elected after that date shall be entitled to compound for the annual subscription by a single payment of fifteen guineas.

6. Annual Subscriptions shall be due on the first of January of each year, but Members elected after the first of October shall not be required to pay a subscription for the then current year.

7. The name of any Ordinary Member whose subscription is more than two years in arrear shall be brought before the Council, and an intimation that this action has been taken shall be communicated to the Member. After the expiration of at least one year from that date, the Council shall be empowered to erase the name from the List of Members.

* Adopted at the Anniversary Meetings of November 13, 1900, and November 18, 1902.

Honorary Members.

8. Twenty persons, non-resident in the United Kingdom, may be elected Honorary Members. They shall pay neither entrance fee nor annual subscription.

9. Every candidate for Honorary Membership shall be proposed by two Members of the Council, and the election shall be by the Council, and shall be confirmed at the ensuing general meeting by a majority consisting of three-fourths of the Members present and voting.

Council.

10. The Society shall be governed by a Council, consisting of a President, two Vice-Presidents, a General Secretary, a Foreign Secretary, a Treasurer, an Editor of the Journal, and twelve Ordinary Members.

11. All members of the Society who have served the office of President shall be life-members of the Council.

12. The Council shall be elected annually at the Anniversary Meeting.

13. Four Ordinary Members of Council shall retire annually, and shall not be eligible for re-election until the next Anniversary Meeting.

14. The Council shall prepare a List of Members nominated for election as Officers and Ordinary Members of Council.

15. The election of Council shall be effected by the agency of voting papers containing the List nominated by the Council. They shall be sent by the General Secretary, at least four weeks before the Anniversary Meeting, to every Ordinary Member of the Society, and every such Member shall be entitled to substitute the names of any other Ordinary Members of the Society for those on the List.

16. The voting papers shall be returned by the Members to the General Secretary, and shall be examined at the Anniversary Meeting by two Scrutineers appointed by the Chairman, who shall on their report declare the result of the election. The voting papers need not be signed.

17. The Council shall have power to appoint Officers, and to co-opt Ordinary Members of Council, to fill vacancies in the Council caused by death or resignation during the interval between two Anniversary Meetings.

18. Meetings of the Council shall be summoned by order of the President or the Council; at such meetings three shall be a quorum, of whom

one shall be either the President, a Vice-President, the Treasurer, or the General Secretary.

19. A Report of Council on the work and progress of the Society shall be submitted to each Anniversary Meeting.

Trustees.

20. Two or more Trustees shall be appointed by the Council, and the invested property of the Society shall stand in their names.

21. Composition-fees shall be treated as Capital: a Resolution of the Society at a general meeting, summoned with notice of a proposed disposition of property, shall be sufficient authority to the Trustees to give effect to such disposition; provided that a resolution of the Council shall be sufficient authority for any change of investment.

Meetings.

22. Meetings of the Society shall be summoned from time to time, as may be deemed necessary by the Council, or at the requisition of any ten Members of the Society. One of these meetings in each year shall be termed the Anniversary Meeting.

Journal.

23. The Numbers of the *Mineralogical Magazine and Journal of the Society* shall be issued at such intervals as the Council shall determine, and shall be sent, postage paid, to every Member of the Society.

Auditors and Balance Sheet.

24. Two Ordinary Members of the Society, one of whom is not a Member of the Council, shall be appointed annually by the Council to audit the accounts of the Society.

25. No auditor shall serve for more than three years in succession.

26. The audited Balance Sheet, after submission to the Council, shall be published in the Journal of the Society as early as possible in every year.

Expulsion of Members.

27. A majority consisting of three-fourths of the whole Council shall have power to expel a Member from the Society, but a Member who

has been expelled shall have a right of appeal to the Society. Notice of such appeal to the Society shall be sent by such Member to the General Secretary within four weeks of the expulsion, and the appeal shall be considered by the Society at the next Anniversary Meeting; a majority of the votes recorded at such Meeting sufficing to confirm or annul the decision of the Council.

Alteration of the Bye-Laws.

28. The Bye-laws may be altered only at an Anniversary Meeting, and only by a majority consisting of three-fourths of the Members present and voting. Notice of changes proposed to be made in the Bye-laws shall be communicated by the General Secretary to every Ordinary Member of the Society at least four weeks before the Anniversary Meeting at which they are to be considered.

Obligation Book.

29. Ordinary Members, by payment of their entrance fee, signify their acceptance of any Bye-laws approved by the Society; and every Member of the Society shall sign an Obligation Book.

LIST OF MEMBERS.

(*November*, 1916.)

HONORARY MEMBERS.

Year of Election.

1905 BAUMHAUER, Heinrich. Professor of Mineralogy in the University of *Freiburg, Switzerland.*

1909 BECKE, Friedrich Johann. Professor of Mineralogy and Petrography in the University of *Vienna.*

1895 BRÖGGER, Waldemar Christofer. Professor of Mineralogy and Geology, and Rector of the University, *Christiania.*

1909 CESÀRO, Giuseppe. Professor of Mineralogy in the University of *Liége.*

1913 CLARKE, Frank Wigglesworth. Chief Chemist, *United States Geological Survey, Washington, D.C., U.S.A.*

1897 DANA, Edward Salisbury. Yale University, *New Haven, Conn., U.S.A.*

1910 FEDOROV, Evgraf Stepanovič. Professor of Mineralogy in the Institute of Mines (Gornyi Institut) of the Empress Catherine II, *Vassili Ostrov, Petrograd.*

1912 GOLDSCHMIDT, Victor. Professor of Mineralogy in the University of Heidelberg. 9 *Gaisbergstrasse, Heidelberg.*

1877 GROTH, Paul Heinrich von. Professor of Mineralogy in the University of Munich. *Brieffach, München VI.*

1900 LACROIX, Alfred. Professor of Mineralogy in the Muséum National d'Histoire Naturelle. 61 *Rue de Buffon, Paris.*

C[1] LANG, Victor von. Professor of Physics in the University of Vienna. *Physikalisches Institut der Universität, Vienna.*

1903 LIEBISCH, Theodor. Professor of Mineralogy in the University of Berlin. *Mineralogisch-petrographisches Institut, Invalidenstrasse* 43, *Berlin No.* 4.

1879 TSCHERMAK, Gustav von. The University, *Vienna.*

1912 VIOLA, Carlo Maria. Professor of Mineralogy in the University of *Parma, Italy.*

1913 WALLERANT, Frédéric. Professor of Mineralogy in the University, *Laboratoires à la Sorbonne, Paris.*

[1] C = Corresponding Member of the Crystallological Society at the time of the amalgamation of the two Societies, December 11, 1883.

Year of Election.

Petrology, Imperial College of Science and Technology, South Kensington, London, S.W. 75 *Craven Park Road, Willesden Junction, London, N.W.*

A 1915 Fermor, Lewis Leigh, A.R.S.M., D.Sc. (Lond.), F.G.S. Superintendent, *Geological Survey of India, Calcutta.*

L C Fletcher, Sir Lazarus, Kt., M.A., Hon. Ph.D. (Berlin), Hon. LL.D. (St. Andrews), F.R.S. Director of the British Museum (Natural History), Cromwell Road, London, S.W. 35 *Woodville Gardens, Ealing, London, W.*

L 1895 Fletcher, Rev. Mark, M.A., F.G.S. Lecturer in Mineralogy in the Armstrong College, Newcastle-on-Tyne. *The Vicarage, Long Benton, Newcastle-on-Tyne.*

L 1902 Flett, John Smith, M.A., LL.D., D.Sc., F.R.S. Assistant Director, Geological Survey of Scotland. 33 *George Square, Edinburgh.*

A 1912 Gardiner, Clarence Roe. *Care of Messrs. Tiffany & Co., 401 Fifth Avenue, New York, U.S.A.*

L 1876 Geikie, Sir Archibald, O.M., K.C.B., D.Sc., D.C.L., LL.D., Past-President R.S. Formerly Director-General of the Geological Survey of the United Kingdom. *Shepherd's Down, Haslemere, Surrey.*

L 1902 Giles, William B., F.I.C. *The Grange, Leyton, Essex.*

L 1886 Goldschmidt, Victor, Ph.D., Professor of Mineralogy in the University of Heidelberg. 9 *Gaisbergstrasse, Heidelberg, Germany.*

A 1905 Goodchild, Wilbert, M.B., Ch.B. (Edin.). *Blencathra Sanatorium, Threlkeld, Penrith, Cumberland.*

A 1895 Gordon, Rev. John More, M.A., F.G.S. 7 *Moreton Gardens, South Kensington, London, S.W.*

A 1903 Grabham, George Walter, M.A., F.G.S. Geologist to the Sudan Government. *Box* 178, *Khartoum, Sudan.*

A 1913 Graham, Richard Percival Devereux, B.A. (Oxon). Assistant Professor of Mineralogy, *McGill University, Montreal, Canada.*

L 1892 Gregory, John Walter, D.Sc., F.R.S. Professor of Geology in the *University of Glasgow.*

A 1911 Hall, Thomas Clifford Fitzwilliam, F.G.S., Assoc. Inst. M.M. Lecturer in Geology and Mineralogy, *School of Metalliferous Mining, Camborne, Cornwall.*

Year of Election.

A 1912 HALLIMOND, Arthur Francis, M.A., F.G.S. Assistant Curator, *Museum of Practical Geology*, 28 *Jermyn Street, London, S.W.*

A 1908 HARGER, Harold Scott, F.G.S. *P. O. Box* 1945, *Johannesburg, Transvaal.*

A 1885 HARKER, Alfred, M.A., LL.D., F.R.S. Fellow of St. John's College, Cambridge. *St. John's College, Cambridge.*

L 1900 HARTLEY, Harold Brewer, M.A., F.C.S. *Balliol College, Oxford.*

A 1910 HATCH, Frederick Henry, Ph.D., M.I.M.M., F.G.S. 15 *Copse Hill, Wimbledon, Surrey.*

A 1910 HENSON, Mrs. F., 29 *St. James Avenue, Brighton.*

A 1879 HENSON, Samuel, 29 *St. James Avenue, Brighton.*

A 1910 HESLOP, Miss Mary Kingdon, M.Sc. Demonstrator in Mineralogy in the Armstrong College, Newcastle-on-Tyne. 20 *Framlington Place, Newcastle-on-Tyne.*

L 1907 HILTON, Harold, M.A., D.Sc. Professor of Mathematics in the University of London. 108 *Alexandra Road, South Hampstead, London, N.W.*

A 1888 HOFFMANN, G. Christian, LL.D. *Care of A. F. May, Esq., Carleton Chambers,* 74 *Sparks Street, Ottawa, Canada.*

L 1896 HOLLAND, Sir Thomas Henry, K.C.I.E., A.R.C.S., D.Sc., F.R.S. Formerly Director of the Geological Survey of India. Professor of Geology and Mineralogy in the Victoria University of Manchester. *Westwood, Alderley Edge, Manchester.*

A 1914 HOLMES, Arthur, D.I.C., A.R.C.S., B.Sc., F.G.S. Demonstrator in Geology, *Imperial College of Science and Technology, South Kensington, London, S.W.*

A 1908 HOPKINS, Edward. 58B *Hatton Garden, London, E.C.*

A 1902 HOWE, John Allen, B.Sc., F.G.S. Curator of the Museum of Practical Geology. *The Museum,* 28 *Jermyn Street, London, S.W.*

A 1878 HUGHES, Thomas McKenny, M.A., F.R.S. Professor of Geology in the University of Cambridge. *Ravensworth, Brooklands Avenue, Cambridge.*

L 1890 HUTCHINSON, Arthur, M.A., Ph.D., F.C.S., F.G.S. Demonstrator in Mineralogy in the University of Cambridge. *Pembroke College, Cambridge.*

	Year of Election.	
A	1905	Jones, Bernard Mouat, M.A., F.C.S. Assistant Professor of Chemistry, *Imperial College of Science and Technology, South Kensington, London, S.W.*
A	1908	Jones, Owen Thomas, M.A., D.Sc., F.G.S. Professor of Geology in the University College of Wales. *University College, Aberystwith.*
L	1876	Kinch, Edward, F.C.S., F.I.C. Formerly Professor of Chemistry in the Royal Agricultural College, Cirencester. *'Sunnyside', Chislehurst, Kent.*
L	1876	Kitto, Benedict, F.I.C., F.G.S. 26 *Lancaster Road, Finsbury Park, London, N.*
A	1909	Knowles, Thomas, B.A., B.Sc. *School of Metalliferous Mining, Camborne, Cornwall.*
A	1907	Krantz, Friedrich Ludwig Robert, Ph.D. 36 *Herwarth-strasse, Bonn, Rhenish Prussia.*
A	1885	Kunz, George Frederick, M.A., Ph.D., Sc.D., F.G.S. 401 *Fifth Avenue, New York City, U.S.A.*
A	C	Lewis, William James, M.A., F.R.S., Professor of Mineralogy in the University of Cambridge. *The New Museums, Cambridge.*
L	C	Liveing, George Downing, M.A., Hon.Sc.D., F.R.S. Formerly Professor of Chemistry in the University of Cambridge. *Newnham, Cambridge.*
L	1876	Liversidge, Archibald, M.A., A.R.S.M., LL.D., F.R.S. Formerly Professor of Chemistry in the University of Sydney, New South Wales. *'Fieldhead', George Road, Coombe Warren, Kingston, Surrey.*
A	1879	Louis, Henry, M.A., D.Sc., A.R.S.M., F.G.S. Professor of Mining in the *Armstrong College, Newcastle-on-Tyne.*
A	1910	MacAlister, Donald Alexander, A.R.S.M., F.G.S. 26 *Thurloe Square, South Kensington, London, S.W.*
A	1914	Macgregor, Alexander Miers, B.A. *Rhodesia Museum, Bulawayo, Rhodesia, South Africa.*
A	1902	McGrigor, George Duncan, F.R.G.S. *Penlee, Alexandra Road, Penzance, Cornwall.*
A	1908	McLintock, William Francis Porter, B.Sc. *The Royal Scottish Museum, Edinburgh.*
A	1902	Maitland, Andrew Gibb, C.E., F.G.S. Government Geologist *Geological Survey, Perth, Western Australia.*

	Year of Election.	
L	1881	MALLET, Frederick Richard, F.G.S., F.C.S., F.I.C. 20 *King's Avenue, Ealing, London, W.*
A	1907	MEARS, James Bartholomew, L.R.C.P., L.R.C.S. (Edin.). *Leuchars, Fifeshire.*
A	1902	MENNELL, Frederic Philip, F.G.S. *Bulawayo, Rhodesia, South Africa.*
L	1876	MERRY, J. S., F.C.S. *Swansea, South Wales.*
L	C	MIERS, Sir Henry Alexander, Kt., M.A., D.Sc., F.R.S. Vice-Chancellor of the University of Manchester. *Birch Heys, Cromwell Range, Fallowfield, Manchester.*
A	1912	MORGAN, Arthur Henry, A.M.I.C.E., M.I.M.M. Superintendent of the *Ruby Mines, Mogok, Upper Burma.*
L	1876	MORRIS, James. 23 *Brynymôr Crescent, Swansea, South Wales.*
A	1915	PARSONS, Arthur Leonard. Assistant Professor of Mineralogy, *University of Toronto, Canada.*
L	1880	PEARCE, Richard, Ph.D., F.G.S. 6 *Beach Lawn, Waterloo, Liverpool.*
L	1899	POLLARD, William, M.A., D.Sc., F.G.S., F.C.S. *Oakfield, Hitchin, Hertfordshire.*
A	1891	POPE, William Jackson, M.A., M.Sc., F.R.S. Professor of Chemistry in the University of Cambridge. *Holmesdale, Brooklands Avenue, Cambridge.*
A	1910	PORTER, Miss Mary Winearls. 76 *Banbury Road, Oxford.*
L	1887	PRIOR, George Thurland, M.A., D.Sc., F.R.S. Keeper of Mineral Department in the *British Museum* (*Natural History*), *Cromwell Road, London, S.W.*
L	1908	RAISIN, Miss Catherine Alice, D.Sc., F.L.S. *Bedford College for Women* (*University of London*), *York Gate, Regent's Park, London, N.W.*
A	1903	RASTALL, Robert Heron, M.A., F.G.S. *Christ's College, Cambridge.*
A	1915	RICHARDSON, William Alfred, B.Sc., F.G.S. Lecturer in Civil Engineering, *University College, Nottingham.*
A	1914	ROGERS, Arthur William, M.A., Sc.D., F.G.S. Director of the Geological Survey of the Cape of Good Hope, *Cape Town, South Africa.*
A	1913	ROGERS, Austin Flint, A.M., Ph.D. Associate Professor of Mineralogy and Petrography, *Leland Stanford Junior University, Palo Alto, California, U.S.A.*

	Year of Election.	
A	1902	Russell, Arthur Edward Ian Montagu. *Swallowfield Park, Reading.*
A	1912	Schaller, Waldemar Theodore, Ph.D. *United States Geological Survey, Washington, D.C., U.S.A.*
A	1908	Schröder, Robert. 17 *Leopoldstrasse, Heidelberg, Germany.*
A	1914	Scott, Alexander, M.A., D.Sc. 137 *St. Andrew's Road, Pollokshields, Glasgow.*
A	1903	Scrivenor, John Brooke, M.A., F.G.S. Geologist to the Federated Malay States. *Kuala Lumpur, Federated Malay States.*
A	1884	Seligmann, Gustav. 6 *Neustadt, Coblenz, Rhenish Prussia.*
A	1908	Shand, Samuel James, D.Sc., Ph.D. Professor of Geology, *Victoria College, Stellenbosch, South Africa.*
A	1912	Simpson, Edward Sydney, B.E., F.C.S. Chemist, Geological Survey of Western Australia. *'Carlingford', Mill Point, South Perth, Western Australia.*
L	1897	Smith, George Frederick Herbert, M.A., D.Sc., F.G.S., F.R.A.S. *British Museum (Natural History), Cromwell Road, London, S.W.*
A	1911	Smith, Herbert Gladstone, B.Sc., A.R.C.S., F.G.S. Demonstrator in Geology, *Imperial College of Science and Technology, South Kensington, London, S.W.*
A	1910	Smith, Walter Campbell, M.A., F.G.S. *British Museum (Natural History), Cromwell Road, London, S.W.*
A	C	Solly, Richard Harrison, M.A. *'The Beehive', Half Key, Malvern.*
A	1894	Spencer, Leonard James, M.A., F.G.S. *British Museum (Natural History), Cromwell Road, London, S.W.*
A	1883	Teall, Sir J. J. Harris, Kt., M.A., LL.D., D.Sc., F.R.S. Formerly Director of the Geological Survey of Great Britain and of the Museum of Practical Geology. 174 *Rosendale Road, West Dulwich, S.E.*
A	1903	Thomas, Herbert Henry, M.A., Sc.D., F.G.S. Geological Survey of England. *The Museum,* 28 *Jermyn Street, London, S.W.*
L	1877	Trechmann, Charles Otto, J.P., Ph.D., F.G.S. *Hudworth Tower, Castle Eden, Co. Durham.*
A	1891	Tutton, Alfred Edwin Howard, M.A., D.Sc., F.R.S. *Duart, Willowby Park, Yelverton, South Devon.*

	Year of Election.	
A	1913	WALKER, Thomas Leonard, M.A., Ph.D., F.G.S. Professor of Mineralogy and Petrography in the *University of Toronto, Canada.*
L	1894	WATTS, William Whitehead, M.A., M.Sc., Sc.D., LL.D., F.R.S. Professor of Geology in the *Imperial College of Science and Technology, South Kensington, S.W.*
A	1913	WAY, Rev. John Pearce, D.D. *Moorlands, Exmouth.*
L	1895	WEBB, R. C.
L	1901	WESTON, Digby St. A. P., Commander, Royal Navy (Retired). 132 *Cromwell Road, London, S.W.*
L	1876	WILLS, Joseph Lainson, F.C.S. *Care of Stifel Union Brewery, St. Louis, Missouri, U.S.A.*
L	1896	WILLS, Louis.
L	C	WOODWARD, Charles J., B.Sc., F.G.S. *The Lindens, St. Mary's Road, Harborne, Birmingham.*
A	1902	YOUNG, Alfred Prentice, Ph.D., F.G.S. *Care of Messrs. Grindlay & Co.*, 54 *Parliament Street, London, S.W.*
A	1914	ZEALLEY, Arthur Edward Victor, A.R.C.S., F.G.S. Geological Survey of Southern Rhodesia. *P. O. Box* 168, *Bulawayo, Rhodesia, South Africa.*

SOCIETIES, INSTITUTIONS, ETC.

To which the Publications of the Mineralogical Society are sent.

(Those sending Publications in Exchange are marked with an asterisk.)

LONDON: Royal Society, *Burlington House, W.*
Geological Society „ „
Chemical Society „ „
British Museum (Natural History), *South Kensington, S.W.*
*Museum of Practical Geology, 28 *Jermyn Street, S.W.*
*Imperial Institute, *South Kensington, S.W.*
*Institution of Mining and Metallurgy, 1 *Finsbury Circus, London, E.C.*

OXFORD: Department of Mineralogy, University Museum.

NEWCASTLE-ON-TYNE: *North of England Institute of Mining Engineers.

TRURO: *Royal Institution of Cornwall.

HULL: Yorkshire Naturalists' Union. (*T. Sheppard, The Municipal Museums, Hull.*)

LIVERPOOL: *Geological Society, *Royal Institution.*

EDINBURGH: Royal Society.
*Geological Society, *India Buildings, George IV Bridge.*

GLASGOW: University of Glasgow.
*Geological Society, 207 *Bath Street.*

DUBLIN: Royal Irish Academy, 19 *Dawson Street.*

PARIS: *Société française de Minéralogie, *Sorbonne.*

BRUSSELS: Société belge de Géologie, de Paléontologie et d'Hydrologie.

LIÉGE: *Société géologique de Belgique.

LEIPZIG: *Zeitschrift für Krystallographie und Mineralogie. (*Dr. Stefan Kreutz, Basztowa 3, Krakau, Galicia, Austria.*)

STUTTGART: Neues Jahrbuch für Mineralogie, &c. (*Schweizerbart'sche Verlagshandlung*).

BERLIN: Zeitschrift für praktische Geologie. (*Prof. Max Krahmann, Berlin NW 40, Neues Tor 1.*)

MUNICH: Technische Hochschule.

HALLE: K. Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.

VIENNA: *K.-K. Naturhistorisches Hofmuseum, *Burgring.*
K.-K. Geologische Reichsanstalt.
*Tschermak's Mineralogische und Petrographische Mitteilungen. (*Prof. F. Becke, Mineralogisches Institut der Universität.*)

KOLOCZSVÁR (KLAUSENBURG): Transylvanian National Museum. (*Mineralogisch-Geologisches Institut der Universität.*)
UPSALA: *Kongl. Universitets-Biblioteket.
HELSINGFORS: Administration des Mines.
PETROGRAD: Mineralogical Society.
ROME: *Ufficio Geologico, *Via Sta. Susanna.*
NAPLES: *Società Reale, Accademia delle Scienze Fisiche e Matematiche.
PISA: *Società Toscana di Scienze Naturali.
*Il Nuovo Cimento. (*A. Battelli.*)
PADOVA: *Rivista di Mineralogia e Cristallografia. (*Prof. R. Panebianco, The University.*)
BUCAREST: Institut Géologique de Roumanie.
SIMLA: The United Service Institution of India.
HONG-KONG: The University Library.
MELBOURNE: *Geological Survey Library, Department of Mines.
SYDNEY: *Royal Society of New South Wales.
*Australian Museum.
WELLINGTON: New Zealand Institute.
BULAWAYO: *Rhodesia Scientific Association, *P. O. Box* 240.
CAPE TOWN: *South African Association for the Advancement of Science, *P. O. Box* 1497.
KIMBERLEY (South Africa): Alexander McGregor Memorial Museum.
NEW BRUNSWICK: Department of Mines, Nova Scotia.
WASHINGTON (D. C.): *United States Geological Survey.
Smithsonian Institution.
NEW YORK: *American Institute of Mining Engineers, 29 *West 39th Street, New York City.*
NEW HAVEN (Conn.): *American Journal of Science.
PHILADELPHIA (Penn.): Academy of Sciences.
BALTIMORE (Maryland): Johns Hopkins University.
CHICAGO: University of Chicago (Journal of Geology).
LANCASTER (Penn.): Economic Geology, 41 *North Queen Street.*
BERKELEY (California): University of California.
MANILA (Philippine Islands): *Bureau of Government Laboratories.
BUENOS AYRES: *Sociedad Científica Argentina.

PROCEEDINGS

OF THE

MINERALOGICAL SOCIETY.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, November 9, 1915, *at* 5 *p.m.*

Dr. A. E. H. Tutton, F.R.S., President, in the Chair.

Mr. William Alfred Richardson was provisionally elected an Ordinary Member of the Society. The death of Mr. T. J. Gibb was announced.

The approval of the Council was given to the Trustees for conversion of the Society's holding of 2½ % Consols into 4½ % War Loan.

The following were selected as the dates of the meetings in 1916: Tuesdays, January 18, March 21, June 20, and November 7 (Anniversary Meeting).

The draft Annual Report of Council, submitted by the Secretary, was read and approved.

A vote of thanks was passed to Dr. G. F. Herbert Smith for sending notices of the meetings of the Society to 'Nature', and other periodicals.

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, November 9, 1915, *at* 5.30 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Twenty-one Members and two Visitors were present.

The election of Mr. W. A. Richardson as an Ordinary Member of the Society was confirmed.

The President nominated Messrs. Barker and Hilton to act as scrutineers of the voting-papers for the election of Officers and Council. The scrutineers reported that forty-one voting-papers had been returned

to the Secretary, and that the list as nominated by the Council was approved, namely :

President. W. Barlow, F.R.S.
Vice-Presidents. Prof. H. L. Bowman, M.A., D.Sc., F.G.S.
A. Hutchinson, M.A., Ph.D., F.G.S.
Treasurer. Sir William P. Beale, Bart., K.C., M.P., F.G.S., F.C.S.
General Secretary. G. T. Prior, M.A., D.Sc., F.R.S.
Foreign Secretary. Prof. W. W. Watts, LL.D., Sc.D., F.R.S.
Editor of the Journal. L. J. Spencer, M.A., F.G.S.

Ordinary Members of Council.

F. N. Ashcroft, M.A., F.C.S.
T. V. Barker, M.A., B.Sc., F.C.S.
G. Barrow, F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
J. W. Evans, LL.B., D.Sc., F.G.S.
Prof. H. Hilton, M.A., D.Sc.
F. H. Hatch, Ph.D., F.G.S.
J. Allen Howe, B.Sc., F.G.S.
F. P. Mennell, F.G.S.
Arthur Russell.
W. Campbell Smith, M.A., F.G.S.
J. J. Harris Teall, M.A., LL.D., D.Sc., F.R.S.

The following ANNUAL REPORT OF COUNCIL was read :—

During the Session 1914–15 four meetings have been held (by kind permission) in the Apartments of the Geological Society, Burlington House, W., at which twenty-one papers were read. Two numbers of the Journal have been issued, viz. No. 80 published in December 1914 and No. 81 in September 1915. These contain seventeen papers, two of which by Prof. G. Cesàro, of Liége, now an exile in England, are in the original French.

The balance-sheet of the year ending December 31, 1914, shows that the financial position of the Society continues to be satisfactory. The assets (exclusive of the Library and stock of the Journal) amounted to £891 7*s.* 10*d.*, and the liabilities to £13 2*s.* 2*d.* The value of the Stock invested in the names of the Trustees of the Society was on that date £756 13*s.* 2*d.*, corresponding to £14 5*s.* 6*d.* for each Life-Member. During the Session a further donation of £5 was voted towards the expenses of publication of the International Annual Tables of Constants.

During the Session 1914–15 the Society has lost by death one Honorary Member, Prof. G. Strüver, two past-Presidents, Sir Arthur Church and Dr. Hugo Müller, and four Ordinary Members. One Ordinary Member has resigned. Two Ordinary Members have been elected. The total number of members on November 8, 1915, was 141, of whom sixteen are Honorary. Of the Ordinary Members fifty-three have compounded for their annual subscription.

The Council has to congratulate the Society on its continued scientific activity and prosperity during the war.

On the motion of Mr. Mennell, seconded by Mr. Collingridge, the Report was adopted.

A vote of thanks to the Council of the Geological Society for permission to meet in the Apartments of the Society was carried.

The dates of meeting for 1916, proposed by the Council, were approved.

The following papers were then read :—

1. Crystallographic relations of allied substances traced by means of the law of valency-volumes : by Mr. W. Barlow (vol. xvii, p. 314).

2. On Torbernite : by Mr. A. F. Hallimond (vol. xvii, p. 326).

3. On the solution of the problem of four tautozonal poles : by Mr. T. V. Barker.

4. Crystals of iron phosphide from a blast-furnace : by Mr. L. J. Spencer (vol. xvii, p. 340).

5. The meteoric stone of Cronstad, Orange River Colony (p. 10).

Mr. G. Barrow exhibited a new magnetic separator, and Dr. Tutton showed models of crystals made with plates of mica.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 18, 1916, *at* 4.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

It was decided that original members of the Society who are still paying annual subscriptions should be made life-members.

Prof. C. G. Cullis and Dr. Herbert Smith were elected Auditors of the accounts for the year ending December 31, 1915.

The President, the General Secretary, and the Editor, in conjunction with Sir Lazarus Fletcher and Sir Henry Miers, were appointed Editorial Committee for the Journal.

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 18, 1916, *at* 5.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Nineteen Members and three Visitors were present.

The following papers were read :—

1. A simple demonstration of the law of Miller : by Prof. G. Cesàro (vol. xvii, p. 324).

2. The meteorite of Daniel's Kuil: by Dr. G. T. Prior (p. 13).

3. On the relationships of meteorites: by G. T. Prior (p. 26).

4. The isolation of the directions-image of a section of a mineral in a rock-slice: by Dr. J. W. Evans (p. 45).

5. A new method of determining the angular direction represented by a point in the directions-image: by Dr. J. W. Evans (p. 52).

6. A (seventh) list of new mineral names: by Mr. L. J. Spencer (vol. xvii, p. 344).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, March 21, 1916, *at* 5 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

The audited balance-sheet for the year ending December 31, 1916, was approved, and the Secretary was instructed to insert it in the Minutes and to publish it in the next number of the Journal.

The deaths of Prof. E. Ludwig and Prof. J. W. Judd were announced, and the Secretary was requested to send a letter of condolence to Mrs. Judd.

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Eighteen Members and one Visitor were present.

The following papers were read:—

1. An improvement in the methods of determining the refractive indices of minerals under the microscope: by Dr. J. W. Evans.

2. On the alteration of Tourmaline: by Dr. William R. Jones.

3. A butterfly-twin of Gypsum: by Mr. L. J. Spencer (p. 82).

Dr. Tutton drew attention to an interesting phenomenon in calcite when cut in a special form of prism; and Dr. Jones exhibited specimens in illustration of his paper.

On the motion of Mr. Mennell, seconded by Mr. Collingridge, the Report was adopted.

A vote of thanks to the Council of the Geological Society for permission to meet in the Apartments of the Society was carried.

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Dr. Tutton drew attention to an interesting phenomenon in calcite when cut in a special form of prism; and Dr. Jones exhibited specimens in illustration of his paper.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, June 20, 1916, *at* 5 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

The death of Mr. J. H. Collins, one of the founders of the Society, was announced.

The following changes in the list of Officers and Council were approved for recommendation to the Members of the Society: Ordinary Members of Council—Messrs. Collingridge, Hopkins, Herbert Smith, and Thomas (and if necessary Mr. Crook) in place of the four retiring Members of Council, Messrs. Ashcroft, Hilton, Russell, and Sir J. J. H. Teall.

The Editor's proposal to advertise for sale at a low price sets of the Journal, in order to reduce the large stock, was approved.

GENERAL MEETING.

Held in the Apartments of the Geological Society, June 20, 1916, *at* 5.30 *p.m.*

Mr. W. Barlow, F.R.S., President, in the Chair.

Fifteen Members were present.

The following papers were read:—

1. The meteorites of Khairpur and Soko-Banja: by Dr. G. T. Prior (pp. 17 and 22).

2. The classification of meteorites: by Dr. G. T. Prior (p. 26).

3. The relations of equivalent twinning operations: by Dr. J. W. Evans.

4. On volcanic rocks from Angola: by Mr. A. Holmes (p. 58).

5. Note on a new occurrence of gold in Cornwall: by Mr. Arthur Russell.

6. Spencerite, a new zinc phosphate from British Columbia: by Prof. T. L. Walker (p. 76).

7. On a magnesian Tourmaline from Renfrew, Canada: by Dr. E. L. Bruce.

Specimens of spencerite and of volcanic rocks from Angola were exhibited.

Receipts.	£ s. d.	£ s. d.
Balance from 1914—		
Bank	81 7 9	
Office	4 1	
		81 11 10
Subscriptions—(1) current	45 2 0	
(2) arrears	17 17 0	
(3) advance	2 2 0	
		65 1 0
Entrance fees		3 3 0
Sale of publications—		
By Publishers	32 14 10	
„ G. Savigar	8 0	
		33 2 10
Dividends—		
Consols	25 13 5	
War Loan (1 December)	15 5 7	
		40 19 0
		£223 17 8

Payments.	£ s. d.	£ s. d.
Printing Magazine (No. 80)	13 2 9	
Authors' copies	3 7 0	
Illustrations	3 9 6	
		19 19 3
Printing Magazine (No. 81)	28 15 0	
Authors' copies	5 1 6	
Illustrations	5 6 0	
		39 2 6
Miscellaneous Printing (Williams & Strahan)		5 15 6
Editor's Honorarium (1914)		10 10 0
G. Savigar for care of stock of Publications (1914)		1 1 0
Librarian (Prof. W. J. Lewis) for binding		1 0 0
Porter's Fee at meetings		1 0 0
Fee for manipulating lantern (1914)		10 0
Donation to 'Tables Annuelles de Constantes'		5 0 0
Postage and Parcels—		
Magazine	3 12 10	
G. Savigar (1914)	7 11	
Hon. Secretary (1914)	3 11	
Hon. Treasurer (1914)	9 4	
		4 14 0
Investments—		
Re-investing dividends	12 5 3	
Investment out of balance	45 0 0	
Paid on conversion of Consols into War Stock	6 8 0	
Broker's fees	6 0	
		63 19 3
Bank Charges		9
Balance at Bank	75 8 6	
Less Office debit	4 3 1	
		71 5 5
		£223 17 8

Examined and compared with the vouchers, and found correct.
11 *February*, 1916.

(*Signed*) C. GILBERT CULLIS, G. F. HERBERT SMITH } Auditors.

BALANCE SHEET.

DECEMBER 31, 1915.

LIABILITIES.	£	s.	d.
Owing for Editor's Honorarium (1915)	10	10	0
,, G. Savigar for care of stock of Publications (1915)	1	1	0
,, Do. for postage (1915)		5	11
,, Hon. Secretary for postage (1915)		8	7
,, Hon. Treasurer for postage (1915)		10	4
,, fee for manipulating lantern (1915)	1	0	0
Excess of assets over liabilities	897	11	11
	£911	7	9

ASSETS.	£	s.	d.	£	s.	d.
Balance at Bank	75	8	6			
Less debit Balance in Office	4	3	1			
				71	5	5
War Loan, £798 8*s*. 4*d*. (valued at 97)				774	18	8
Sale of Publications (1915)—						
Owing from Publishers	20	8	2			
,, G. Savigar	2	15	6			
				23	3	8
Arrears of Subscriptions (58) valued at				42	0	0
				£911	7	9

Number of Life Members, 53.

The stock of Publications and the value of the Library are not included in the above assets.

(*Signed*) WM. P. BEALE,
Hon. Treasurer.
18 February, 1916.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 83. NOVEMBER, 1916. Vol. XVIII.

The Meteoric Stones of Launton, Warbreccan, Cronstad, Daniel's Kuil, Khairpur, and Soko-Banja.[1]

(*With Plates I–IV.*)

By G. T. Prior, M.A., D.Sc., F.R.S.

Keeper of the Mineral Department of the British Museum.

[Read March 16, June 15, November 9, 1915; January 18, June 20, 1916.

THE investigation of the Launton, Warbreccan, and Cronstad meteorites was undertaken with the object of placing on record descriptions of these stones. Launton and Warbreccan were found to conform very well with the type of Baroti and Wittekrantz, containing from 7–9 per cent. of nickel-iron, described in a previous paper.[2] Cronstad, however, which contained as much as 18 per cent. of nickel-iron, showed so much variation from that type as to suggest a passage towards the rare Hvittis class of chrondritic stone containing even larger amounts of nickel-iron. The scope of the paper was therefore

[1] Communicated by permission of the Trustees of the British Museum.

[2] G. T. Prior, Mineralogical Magazine, 1913, vol. xvii, p. 22.

widened by investigations of the Daniel's Kuil and Khairpur meteorites, which in thin sections were found to resemble strikingly the Hvittis stone. Finally, a new analysis of the Soko-Banja meteorite was made in order to test whether the interrelation between the amount and chemical composition of the nickel-iron and the chemical composition of the ferromagnesium minerals, which had been found to subsist between Baroti and stones containing much larger amounts of nickel-iron, also extended in the opposite direction to stones containing smaller amounts.

Launton.

According to the description published soon after its fall by Mr. William Stowe, a surgeon of Buckingham,[1] the Launton meteoric stone fell 'on Monday, the 15th day of February, 1830, at half-past seven in the evening, in the garden of John Bucknell, a labourer in the employment of Mr. Cross, farmer, at Launton, near Bicester, Oxon. Its descent was accompanied with a most brilliant light, which was visible for many miles around, and attended with a *triple* explosion, which was described to me, by a person who heard it at the distance of four miles, as resembling the rapid discharge of three ordinary guns. It penetrated some newly dug mould nearly a foot deep; and, though seen to strike the earth, was not sought for till the following morning when, of course, it had become cold. A man named Thomas Marriot was passing near the garden at the moment, and states that it came rapidly towards him from the north-east, not perpendicularly but *obliquely*, appearing about the size of a cricket-ball.'

The stone, which weighed 2 lb. 5 oz., soon after its fall passed into the possession of the Rev. Dr. John Lee of Hartwell House, near Aylesbury, who declined to part with any of it to other collectors. In 1853, however, he presented a cast of the stone to the British Museum. A note on the fall of the stone was sent by Professor W. H. Miller of Cambridge in 1841 to Poggendorff's Annalen der Physik und Chemie (vol. liv, p. 291), in which he states that he had obtained the particulars from a catalogue in Dr. Lee's house in London. A brief description of the stone is given in 'Aedes Hartwellianae, or Notices of the Manor and Mansion of Hartwell' (1851, p. 141), by Captain W. H. Smyth. It is also mentioned in the same author's 'Cycle of Celestial Objects' (1844, vol. i, p. 163).

The subsequent history of the stone illustrates very strikingly the perils which may beset rare or type specimens preserved in private

[1] W. Stone, Mag. Nat. Hist., 1831, vol. iv, p. 139.

collections, for after Dr. Lee's death the meteorite appears to have been practically lost sight of, until in 1889 inquiry was made about it by the late Sir Arthur H. Church, and later by Sir Lazarus Fletcher, then Keeper of the Mineral Department of the British Museum. On hearing from Mr. Mark Merriman, the son of Dr. Lee's solicitor, that Colonel E. D. Lee still preserved the contents of Dr. Lee's Museum at Hartwell House, Sir Lazarus Fletcher applied to Colonel Lee for information relative to the meteorite, but received the reply that the Launton stone was not in the Hartwell Museum. Nothing daunted, however, in March 1895 he paid a visit to Hartwell House, and was able to point out to Colonel Lee that a meteorite in the Museum labelled Esnandes was none other than the missing Launton stone, as it exactly resembled the model in the British Museum. The identity of the stone was confirmed by the fact that the label in the box containing it bore a number (250) which in the manuscript catalogue of Dr. Lee's collection referred to the Launton meteorite. As a result of this visit, the meteorite, later in the same year, was acquired for the British Museum Collection.

Physical Characters.

The stone (Reg. No. 77528), which is complete except for broken corners, and is covered with the usual dull black crust, measures roughly $4\frac{1}{2} \times 3 \times 2\frac{1}{2}$ inches. Its present weight, after cutting off a small portion for analysis, &c., is 998 grams. The original weight was 1023 grams. Its specific gravity is 3·35, as determined by hydrostatic weighing of the whole stone. In shape the stone is a rough four-sided prism (Plate I, fig. 1), with one terminal face square and smooth and rather smaller than the other, which is irregular and broken. Of the prism faces three are fairly smooth, but the fourth and larger surface is very irregular, showing 'thumb-marks', sharp ridges, and indentations. Beneath the crust the material has the characters of a white to grey (intermediate) chondrite, but brown patches show that the nickeliferous iron has undergone some oxidation: it is traversed by a few thin, black veins.

Under the microscope, a thin section shows no unusual features. Grains of nickel-iron and troilite are seen in a matrix of bronzite and olivine. Chondrules consisting chiefly of radiating bronzite are few and are mostly of irregular shape merging into the matrix. A little interstitial matter between the olivine and bronzite grains is for the most part isotropic and is rendered almost opaque by included black

grains. The section is crossed by several thin veins of dark, opaque material enclosing here and there lenticular patches of olivine and bronzite. Stainings of oxide of iron occur throughout the slide especially along these veins. The above characters show that the stone belongs to the intermediate veined chondrite group, Cia.

Chemical Composition.

The analyses were made by the method described in previous papers.[1] They were conducted with due care, but the determination of minor constituents, such as Pt, Cu, Au, &c.,[2] was not attempted. To effect the division of the material into attracted and unattracted portions a magnetic comb, not so strongly magnetic as to attract the troilite, was used. For the separation of iron and nickel in the attracted material two precipitations with sodium acetate were found to be sufficient, the determination of the nickel being checked by a precipitation with dimethylglyoxime in another portion of the solution. In the determination of the alkalis care was taken to convert into chloride any sulphate resulting from the oxidation of the troilite.

For the analysis a fragment of the meteorite weighing nearly 9 grams was separated by the magnetic comb into an attracted portion weighing 1·0114 grams and an unattracted portion weighing 7·6063 grams. The results of the analyses of the two portions are given below, together with the bulk-analysis obtained by combining these results.

	Attracted.	Unattracted.	Bulk-analysis.
Fe	61·33	—	7·20
Ni	10·24	—	1·20
Co	0·68	—	0·08
Fe	0·58	4·15	3·80
S	0·33	2·38	2·18
SiO_2	4·51	43·55	39·70
TiO_2	—	0·20	0·18
Al_2O_3	—	2·67	2·40
Cr_2O_3	—	0·35	0·31
Fe_2O_3	—	1·66	1·49
FeO	2·52	13·39	12·35
MnO	—	0·32	0·29

[1] G. T. Prior, Mineralogical Magazine, 1913–14, vol. xvii, pp. 24, 132.

[2] On the occurrence of such elements in meteorites see G. P. Merrill, Mem. Nat. Acad. Sciences, Washington, 1916, vol. xiv, p. 1.

	Attracted.	Unattracted.	Bulk-analysis.
NiO ...	— ...	0·13 ...	0·12
CaO ...	0·79 ...	2·21 ...	2·09
MgO ...	4·65 ...	27·05 ...	24·89
K_2O ...	— ...	0·10 ...	0·09
Na_2O ...	— ...	1·12 ...	1·01
P_2O_5 ...	— ...	0·17 ...	0·15
H_2O ...	— ...	0·47 ...	0·42
Insoluble ...	14·32 ...	— ...	—
	99·95	99·92	99·95

In order to determine the composition of the olivine, a portion of the unattracted material weighing about one gram was digested with dilute hydrochloric acid (sp. gr. 1·06), and the soluble portion analysed. To avoid any decomposition of the bronzite and felspar, only a single digestion was made, so that some olivine still remained undecomposed in the insoluble portion. The result of the analysis was as follows:—

SiO_2 ...	17·05
FeO ...	9·25
CaO ...	0·35
MgO ...	17·34
FeS, &c.[1] ...	8·94
Insoluble ...	46·65
	99·58

The composition of the olivine deduced from this analysis is approximately expressed by the formula $3{\cdot}3\ Mg_2SiO_4.Fe_2SiO_4$.

The mineral composition of the meteorite deduced from the bulk analysis and the known composition of the olivine is:—

$NaAlSi_3O_8$ ...	8·54			
$KAlSi_3O_8$ ...	0·56	...	10·82 ...	Felspar.
$CaAl_2Si_2O_8$ ...	1·72			
$FeO.TiO_2$ ...	...	...	0·33	
$FeO.Cr_2O_3$ ...	...	...	0·45 ...	Chromite.
Fe_2O_3 ...	...	...	1·49	
NiO ...	...	...	0·12	
$3Ca_3P_2O_8.CaO$ ...	...	...	0·36 ...	Apatite.

[1] From analysis of unattracted portion.

$CaSiO_3$	...	3·17				
$FeSiO_3$	...	6·31	...	29·50	...	Bronzite.
$MgSiO_3$	...	20·02				
Fe_2SiO_4	...	12·61	...	41·91	...	Olivine.
Mg_2SiO_4	...	29·30				
Fe	...	3·80	...	5·98	...	Troilite.
S	...	2·18				
Fe	...	7·20				
Ni	...	1·20	...	8·48	...	Nickel-iron.
Co	...	0·08				
H_2O			...	0·42	...	Water.
				99·86		

Specific gravity, 3·35.

The analyses show that the Launton meteoric stone contains about $8\frac{1}{2}$ per cent. of nickel-iron, in which the ratio of Fe to Ni is about 6, and olivine and bronzite having chemical compositions represented approximately by the formulae $3{\cdot}3\,Mg_2SiO_4 . Fe_2SiO_4$ and $3CaSiO_3 . 5\,FeSiO_3 . 22MgSiO_3$ respectively. In chemical composition, therefore, the stone belongs to the same type as Baroti and Wittekrantz described in a previous paper.[1]

Warbreccan.

The three stones (Reg. No. 1905, 377–379) of this fall were purchased for the British Museum Collection in 1905 from Mr. B. Warwick, of London, who had obtained them from Mr. T. C. Wollaston of Adelaide. The finder of the stones, Mr. R. Pope, from whom Mr. Wollaston had received them, first heard of them from the natives of central Queensland in 1904. It is probable that they had been seen to fall, for in his letter to Mr. Wollaston giving an account of the find, Mr. Pope speaks of the fear in which the stones were held by the blacks. He says: 'They are deadly afraid of them and cover them up in the bush with Kangaroo grass, twisted gidya bark, and mud, and throw dry boughs over the top. Their idea is if the sun sees them more stones will be shaken down to kill the poor black fellow. They will not go near them, when once covered, nor show the way to any one.' It was with great difficulty, therefore, that, by the aid of an old

[1] G. T. Prior, Mineralogical Magazine, 1913, vol. xvii, p. 22.

stockman who was well acquainted with the district, he was at length enabled to trace the stones. The spot at which they were found was about 40 miles west of Windorah, central Queensland, in the Warbreccan run, 'a rough lonely country', as described by Mr. Pope, 'away from all civilization, in which you can ride all day and see no one'.

Physical Characters.

The shape and size of the three stones are shown in Plates I and II. Two of them are remarkable for their size, which is surpassed by only one other specimen of an aerolite in the British Museum Collection, that of Parnallee. They measure roughly $12 \times 11\frac{1}{2} \times 9$ inches and $14 \times 11 \times 7$ inches respectively. The weights of the three stones are 31,610 grams (about 69 lb.), 29,100 grams (about 64 lb.), and 443 grams (about 1 lb.) respectively. The largest stone seen on the left in Plate I, fig. 2, and in two positions in Plate II, figs. 1 and 2, is pitted with 'thumb-marks' on all its surfaces except on two which are fairly flat and smooth (see Plate II, fig. 2). The dull black crust is thin, and shows few signs of flow of material except near the sharp point seen in Plate II, fig. 1, at the top. Fractured surfaces show small grains of nickel-iron and larger and less uniformly distributed nodules of troilite in a white matrix crossed by a few thin, dark veins, and in parts stained brown by oxidation. The specific gravity of a fragment weighing about 12 grams of this stone is 3·48, as determined by hydrostatic weighing. The other large stone shown on the right in Plate I, fig. 2, and in two positions in Plate II, figs. 3 and 4, is flatter than the first. It has one large, fairly flat and smooth surface (on the left in fig. 4), but the other faces are irregular and pitted with 'thumb-marks', though not so thickly as on the largest stone. The crust of the stone has weathered to a brownish-red colour. The small stone, seen in the centre in Plate I, fig 2, is of very irregular shape with one end sharply pointed. Both crust and fractured surfaces have weathered to a red colour as in the second stone.

Under the microscope, a thin section from the largest stone shows small grains of nickel-iron and troilite in the usual aggregate of olivine and bronzite. Very few chondrules with good circular outline are present. In one section there are only two, one of fibrous bronzite and one of olivine in concentric rings. In another section the only chondrule had an interior consisting of detached grains of olivine in colourless

isotropic material clouded with black inclusions, and an exterior consisting of a broad ring of olivine in optical continuity with the internal grains. The interstitial material between the olivines and bronzites in parts is isotropic, and in parts feebly doubly refractive with refractive index less than Canada balsam. The stone belongs to the white-veined chondrite group Cwa.

Chemical Composition.

For the analyses a fragment cut from the largest stone (1905, 377) and weighing nearly 17 grams was taken. This was crushed and separated by the magnetic comb into an attracted portion weighing 1·5553 grams, and an unattracted portion weighing 14·8902 grams. The results of the analyses are as follows:—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	63·79	—	6·03
Ni	11·23	—	1·06
Co	0·85	—	0·08
Fe	0·68	4·39	4·09
S	0·39	2·51	2·31
SiO_2	3·91	43·13	39·86
TiO_2	—	0·23	0·21
Al_2O_3	—	1·87	1·71
Cr_2O_3	—	0·45	0·41
Fe_2O_3	—	2·35	2·15
FeO	2·23	13·78	12·84
MnO	—	0·43	0·39
NiO	—	0·13	0·12
CaO	trace	2·19	2·01
MgO	4·19	26·57	24·75
K_2O	—	0·08	0·06
Na_2O	—	1·01	0·92
P_2O_5	—	0·28	0·26
H_2O	—	0·87	0·80
Insoluble	11·54	—	—
O and loss	1·19	—	—
	100·00	100·27	100·06

In order to determine the composition of the olivine, an analysis was made of a portion of the unattracted material digested with dilute hydrochloric acid with the following result:—

SiO_2	...	16·60
FeO	...	9·62
MgO	...	18·09
FeS, &c.[1]	...	10·53
Insoluble	...	44·68
		99·52

The composition of the olivine deduced from this analysis is approximately 3·37 $Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition of the meteorite calculated from the bulk-analysis and the composition of the olivine is:—

$NaAlSi_3O_8$	...	7·81				
$KAlSi_3O_8$	...	0.33	...	8·50	...	Felspar.
$CaAl_2Si_2O_8$	...	0·36				
$FeO. Cr_2O_3$	...	...	...	0·60	...	Chromite.
$FeO. TiO_2$	...	...	...	0·39		
Fe_2O_3	...	...	...	2·15		
NiO	...	...	...	0·12		
$3Ca_3P_2O_8. CaO$	...	...	...	0·59	...	Apatite.
$CaSiO_3$	...	3·33				
$FeSiO_3$	...	8·02	..	33·54	...	Bronzite.
$MgSiO_3$	...	22·19				
Fe_2SiO_4	...	12·02	...	39·80	...	Olivine.
Mg_2SiO_4	...	27·78				
Fe	...	6·03				
Ni	...	1·06	...	7·17	...	Nickel-iron.
Co	...	0·08				
Fe	...	4·09	...	6·40	...	Troilite.
S	...	2·31				
H_2O	...		...	0·80	...	Water.
				100·06		

Specific gravity, 3·48.

[1] From analysis of unattracted portion.

The Warbreccan meteorite contains about 7 per cent. of nickel-iron in which the ratio of Fe to Ni is about 6, and olivine and bronzite of which the chemical compositions are represented approximately by the formulae $3{\cdot}4\,Mg_2SiO_4 . Fe_2SiO_4$ and $2CaSiO_3 . 4FeSiO_3 . 15MgSiO_3$ respectively. In chemical composition, therefore, the stone belongs to the same type as Launton and Baroti.

Cronstad (Kroonstad).

The British Museum Collection contains two specimens of this fall. One (52149), now weighing 285 grams, was presented in 1878 by Mr. John Sanderson, and the other (55428) weighing 882 grams was acquired in 1884 by exchange with the Bloemfontein Museum through the Curator, Dr. H. Exton. The following extract from the minutes of the Bloemfontein Museum giving the date of fall of the meteorite is taken from a letter sent by Dr. Exton in 1886 to Mr. T. Davies, then assistant in the Mineral Department of the British Museum :—

'Dec. 8th, 1877.—Presented by His Honour President Brand, portion of a meteoric stone which fell at Cronstadt, O. F. S., on the 19th November, 1877, at about 4 p.m.'

In the same letter Dr. Exton refers to the loud report and flash of light attending the fall of the meteorite, as described in the newspaper report at the time, and states that the facts were well authenticated, having been witnessed by many observers in the large tract of country (18 miles) over which fragments of the meteorite on its rupture were scattered. According to W. Flight,[1] the shower took place in a wooded district, so that few stones could be collected. A short account of the two stones, weighing respectively 1382 and 663 grams, in the Bloemfontein Museum, has been given by Professor W. A. Douglas Rudge.[2]

Of the British Museum specimens, the larger one (Plate III, fig. 2) is a nearly complete stone, being covered with the usual dull black crust except on one fairly flat surface of fracture. The crust is thin and is slightly pitted, but shows little sign of flow of material. The surfaces are fairly smooth, and only show a few 'thumb-marks' on two of them. The other specimen (Plate III, fig. 1) has been cut from a very irregular flat stone, and has a similar pitted crust. One large surface is fairly smooth except for two 'thumb-marks', but the others are very rough and irregular, and one shows a series of fairly deep

[1] W. Flight, 'A Chapter in the History of Meteorites,' 1887, p. 205.
[2] W. A. D. Rudge, Trans. Roy. Soc. S. Africa, 1912, vol. ii, p. 211.

grooves. The specific gravity of this stone is 3·61, as determined by hydrostatic weighing.

A thin section under the microscope shows a few fairly sharply defined chondrules, some of fibrous and radiating bronzite and others of olivine grains, in a granular matrix of olivine and bronzite, with troilite, and much nickel-iron in grains and long, vein-like patches. One chondrule had a curiously indented, circular outline. The stone belongs to the grey chondrite group Cg.

Chemical Composition.

For the analysis a fragment from the smaller specimen (52149), weighing nearly 11 grams, was separated by the magnetic comb, into an attracted portion weighing 2·7414 grams, and an unattracted portion weighing 7·7118 grams. The results of the analyses are as follows :—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	63·72	—	16·71
Ni	5·91	—	1·55
Co	0·88	—	0·23
Fe	0·75	3·94	3·29
S	0·43	2·25	1·88
SiO_2	3·92	46·16	37·24
TiO_2	—	0·38	0·30
Al_2O_3	—	3·08	2·41
Cr_2O_3	—	0·47	0·37
FeO	1·93	11·04	9·17
MnO	—	0·05 [1]	0·04
NiO	—	0·13	0·10
CaO	—	1·85	1·45
MgO	4·30	28·66	23·61
K_2O	—	0·09	0·07
Na_2O	—	0·86	0·67
P_2O_5	—	0·32	0·25
H_2O	—	0·44	0·34
Insoluble	17·79	—	—
	99·63	99·72	99·68

[1] Probably too low, as the separation from iron was by means of ammonia. This applies also to the following analyses, but not to those of Launton and Warbreccan.

An analysis of the portion of the unattracted soluble in dilute hydrochloric acid (sp. gr. 1·06) gave the following result:—

SiO_2	...	14·85
FeO	...	7·49
MgO	...	16·36
FeS, &c.	...	6·63
Insoluble	...	54·78
		100·11

The composition of the olivine deduced from the analysis is approximately 4 $Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition of the meteorite calculated from this result and that of the bulk-analysis is as follows:—

$NaAlSi_3O_8$	...	5·64				
$KAlSi_3O_8$	...	0·39	...	9·43	...	Felspar.
$CaAl_2Si_2O_8$	...	3·40				
$FeO . TiO_2$	...	...	...	0·56		
NiO	...	...	...	0·10		
$FeO . Cr_2O_3$	...	...	...	0·54	...	Chromite.
$3Ca_3P_2O_8 . CaO$	...	...	...	0·56	...	Apatite.
$CaSiO_3$	...	0·94				
$FeSiO_3$	...	5·80	...	35·03	...	Bronzite.
$MgSiO_3$	...	28·29				
Fe_2SiO_4	...	7·97				
Mg_2SiO_4	...	21·47	...	29·44	...	Olivine.
Fe	...	3·29				
S	...	1·88	...	5·17	...	Troilite.
Fe	...	16·71				
Ni	...	1·55	..	18·49	...	Nickel-iron.
Co	...	0·23				
H_2O	...		...	0·34	...	Water.
				99·66		

Specific gravity, 3·61.

The analyses show that Cronstad exhibits some variation from the type to which Baroti, Wittekrantz, Launton, and Warbreccan belong. It contains over 18 per cent. of nickel-iron instead of less than 10, and this iron is much poorer in nickel, the ratio of iron to nickel being about 11

instead of 6 as in Baroti. Moreover, this higher percentage of a nickel-poor iron is associated with a diminished amount of oxide of iron in the ferromagnesium minerals, for the ratios of MgO to FeO in the olivine and bronzite of Cronstad are 4 and 6 respectively, whereas in Baroti they are 3 and 4.

Reference to the list of forty-one analyses of chondritic stones given in a previous paper (loc. cit., pp. 36–37) will show that in most of the stones, which like Cronstad contain higher percentages of nickel-iron than 10 (e.g. Beaver Creek, Cape Girardeau, Utah, and Winnebago County), the nickel-iron is also poor in nickel and there is a similar tendency to a diminution of iron in the ferromagnesium minerals. Now there is a chondritic stone, viz. Hvittis, in which this tendency reaches a limit, for in this stone which contains even higher amounts of a nickel-poor iron than Cronstad, the magnesium silicate is a pure enstatite practically free from iron. The examination of thin sections in the British Museum Collection showed that there were two other stones, viz. Daniel's Kuil and Khairpur, which strikingly resembled the Hvittis stone, and contained like it the mineral oldhamite in fair amount. It was decided, therefore, to make investigations of these two meteorites.

Daniel's Kuil.

The Daniel's Kuil meteorite was first described by J. R. Gregory,[1] who, when in South Africa, had obtained the only stone of the fall from Captain Nicholas Waterboer. It had been given to the latter by the native Griqua, who had witnessed its fall near his hut. According to information supplied to Mr. Gregory by the Rev. James Good, the missionary to whom the native, after bringing it to Griqua Town, showed the stone, it fell on March 20, 1868, at Daniel's Kuil, two days' journey N.N.E. of Griqua Town, Griqualand West, South Africa, and was warm when picked up. The weight of the stone was only 2 lb. 5 oz., and it was in two halves when it came into the possession of Mr. Gregory. The meteorite was brought to London and soon afterwards was partially analysed by Sir Arthur H. Church.[2]

The specimens (42388, 42502, 42503) in the British Museum Collection are fragments of the stone and were all obtained from Mr. Gregory. They now weigh 222, 121, and 88 grams respectively, and fit together

[1] J. R. Gregory, Geol. Mag., 1868, vol. v, p. 531.
[2] A. H. Church, Journ. Chem. Soc., 1869, vol. vii, p. 22.

so as to give a fair idea (Plate III, fig. 4) of the complete stone of which they constitute nearly a half. As seen in the model (Plate III, fig. 3) the complete stone was elongated with rounded surfaces coated with the usual dull black crust. In the specimens the crust shows traces, but not well-marked, of lines of flow of molten material. Fractured surfaces have the peculiar dark grey, hard and rough character shared with Cléguérec, Moti-ka-nagla, and other crystalline stones rich in nickel-iron. The specific gravity, as determined on about 1 gram of material with the pyknometer, is 3·66.

Under the microscope, the section shows much nickel-iron in grains and irregular patches and troilite in smaller grains, in a crystalline matrix which consists, as shown by the following analyses, of a nearly pure enstatite. The stone is in fact precisely similar to Hvittis, and like that meteorite contains a notable amount of oldhamite which in section is seen in patches of reddish-yellow grains, often surrounded by a black reflective ring of what appears to be graphitic material. Chondrules are rare, and consist only of irregular radiating pyroxene. The above characters, coupled with the results of the analyses, show that the meteorite belongs to the rare Hvittis type to which, as shown by Lacroix,[1] Pillistfer also belongs.

Chemical Composition.

The material used for analysis consisted of a fragment of specimen (42502) weighing about 14 grams, which was separated by the magnetic comb into an attracted portion weighing 4·2188 grams and an unattracted portion weighing 9·5458 grams. The results of the analyses of these portions were as follows:—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	77·33	—	23·70
Ni	5·83	—	1·78
Co	0·39	—	0·12
Fe	—	7·03	5·15
S	trace	4·02	2·94
Ca	—	0·65	0·48
S	—	0·52	0·38
SiO_2	3·32[2]	51·12	38·47
TiO_2	—	0·16	0·12

[1] A. Lacroix, Bull. Soc. franç. Min., 1905, vol. xxviii, p. 70.

[2] The percentage of silica is unaccountably high as compared with that of the

	Attracted.	Unattracted.	Bulk-analysis.
Al_2O_3 ...	— ...	2·43 ...	1·78
Cr_2O_3 ...	— ...	0·32 ...	0·23
Cr_2S_3 ...	— ...	0·40 ...	0·29
FeO ...	— ...	0·59 ...	0·23
NiO ...	— ...	0·15 ...	0·11
MnO ...	— ...	0·03 ...	0·02
CaO ...	0·17 ...	1·34 ...	1·03
MgO ...	0·21 ...	29·45 ...	21·63
K_2O ...	— ...	0·21 ...	0·15
Na_2O ...	— ...	0·88 ...	0·64
P_2O_5 ...	— ...	trace ...	trace
H_2O ...	— ...	0·47 ...	0·34
Graphite,[1] &c.	— ...	0·38 ..	0·32
Insoluble	12·65 ...	— ...	—
	99·90	100·15	99·91

The percentage of oldhamite was estimated from the calcium obtained in solution after digesting a portion of the unattracted in water slightly acidified with acetic acid. A portion of the unattracted digested with dilute hydrochloric acid (sp. gr. 1·06) to which some nitric acid was added gave an insoluble residue of enstatite, &c., amounting to 84·58 per cent. The solution contained, besides troilite, daubreelite, and oldhamite, only 0·58 per cent. of SiO_2 and 0·26 per cent. MgO, so that the bulk of the silicates were contained in the insoluble. An analysis of the insoluble after ignition gave the following result:—

SiO_2 ...	59·76
Al_2O_3[2] ...	2·78
FeO ...	0·18
CaO ...	1·31
MgO ...	34·28
Na_2O ...	1·04
K_2O ...	0·25
	99·60

MgO. In the analysis of St. Marks, a stone probably also belonging to the Hvittis type, Cohen noted a similar excess of silica in the soluble portion (Ann. S. African Museum, 1906, vol. v, p. 14), and free silica was also detected in thin sections of the meteorite under the microscope.

[1] Loss on ignition of insoluble.

[2] Containing a little Cr_2O_3.

The small amount of iron obtained in the analysis belongs probably to chromite and not to the enstatite. Much of the chromium appears to have passed into the soluble portion of the unattracted and is therefore in all probability in the form of daubreelite, $FeS.Cr_2S_3$, instead of chromite. In this respect the meteorite is similar to Hvittis in which Borgström determined the presence of daubreelite.[1]

The mineral composition deduced from the analyses is as follows :—

$NaAlSi_3O_8$	...	5·48				
$KAlSi_3O_8$	...	2·01	...	8·47	...	Felspar.
$CaAl_2Si_2O_8$	...	0·98				
$FeO.TiO_2$	...	...	...	0·36		
$FeO.Cr_2O_3$	...	...	...	0·34	...	Chromite.
$FeS.Cr_2S_3$	...	...	...	0·40	...	Daubreelite.
$MgSiO_3$	...	54·01				
$CaSiO_3$	...	1·75	...	55·76	...	Enstatite.
Ca	...	0·48				
S	...	0·38	...	0·86	...	Oldhamite.
Fe	...	5·07				
S	...	2·89	...	7·96	...	Troilite.
Fe	...	23·55				
Ni	...	1·78	...	25·45	...	Nickel-iron.
Co	...	0·12				
H_2O	...		...	0·34	...	Water.
C	...		...	0·32	...	Graphite.
				100·26		

Specific gravity, 3·66.

The result of the investigation of Daniel's Kuil has been to show the precise similarity of this meteorite with the rare type of stone of which Hvittis and Pillistfer, and somewhat doubtfully St. Marks, have been hitherto the only representatives. In this type it would seem that the tendency for the predominence of magnesia over ferrous oxide in the ferromagnesium minerals exhibited by Cronstad and other chrondritic stones rich in nickel-poor nickel-iron reaches its limit, for the only silicate, besides felspar, which the members of the Hvittis class contain, consists of a pure enstatite free from iron.

[1] L. H. Borgström, 'Die Meteoriten von Hvittis und Marjalahti.' Bull. Comm. Géol. Finlande, 1903, vol. iii, No. 14, p. 24.

Khairpur.

An account of the fall of the stones of the Khairpur meteorite was given soon after the event by H. B. Medlicott.[1] The fall took place on September 23, 1873, partly in the state of Bhawalpur and partly in the Multan district, on either side of the Sutlej, the greatest number of stones falling near the village of Khairpur, 72° 12′ E. long., 29° 56′ N. lat., 36 miles east-north-east of Bhawalpur. Of the numerous stones which fell only six appear to have been preserved in the Indian Museums. According to a list given by Medlicott (l. c., p. 34) they are as follows :—

	lb.	oz.	grains.
A. Lahore Museum	10	12	126
B. Indian Museum	9	11	219
C. „ „	7	14	236
D. Geological Museum	1	2	412
E. „ „		3	79
F. „ „		6	70

The first five stones fell at Khairpur and were found 'imbedded in the earth at a depth of about 1½ feet at various places, about a mile and a half from Khairpur to the eastward, and about a mile apart'. The sixth was received from Colonel Ralph Young, Commissioner of Multan, as having fallen near Mylsi. According to Medlicott it is probably one of the seven stones recorded by Captain Lang, Deputy Commissioner for the Multan district, as found on the Multan side, 'four at different spots near Gogewala well, close to E. S. E. of Mahomed Moorut; two at Khurampur on the right bank of the Sutlej, and one at Araoli, two miles N.W. of Khurampur'. The range of the Khairpur meteoric stones is estimated by Medlicott to have had a length of sixteen miles, and a breadth of about three miles. The remarkable phenomena attending the fall were described by the Rev. G. Yeates of the Church Missionary Society, Multan, who observed them from a spot 12 miles south of Multan. At 5.10 a.m., 45 minutes before sunrise, a cluster of luminous meteors, having the appearance of a rocket just bursting, was seen to move steadily from a spot close to the star Algenib, about 15° above the horizon in the west, to a point nearly due east, through nearly 180°, crossing the meridian close under Orion at an altitude of about 50°. The larger fragments of the cluster, taking the lead, glowed with an

[1] H. B. Medlicott, Journ. Asiatic Soc. Bengal, 1874, vol. xliii, p. 33.

intense white light, and were surrounded and followed by a great number of smaller ones, the whole leaving behind a broad brilliant fiery-red train, which continued very bright for some time and was distinctly traceable for more than three-quarters of an hour afterwards, before finally breaking up into silvery-grey clouds which were dispersed by the wind. About four minutes after the first appearance of the meteorite, there was a loud report followed by a long reverberation. A very similar account of the phenomena was given by a correspondent of the 'Pioneer' newspaper of September 30, 1873, who describes the meteorite as appearing first as a brilliant star moving slantingly upwards and towards him, and then bursting almost immediately like a rocket, but without scattering to any extent. All the fragments or stars, numbering twenty, were distinctly visible and moved in parallel courses, each leaving a tail of red light behind it, which blended together to form a huge band of light from one end of the heavens to the other.

The three specimens (51366, 51189, 48369) of the Khairpur meteorite in the British Museum Collection now weigh respectively 3010, 201, and 65 grams. The largest and smallest stones were obtained by exchange from the Calcutta Museum in 1877 and 1875 respectively, and, judging from their original weights of 7 lb. 14 oz. and 1397 grains (3 oz. 84 gr.), are probably the stones C and E of Medlicott's list. The third stone was presented by A. Brandreth through W. G. Spottiswoode in 1877. All three stones are coated with a dull black crust which is so thin that in many places it has been worn away. The largest specimen is a portion of a still larger stone. In the figure (Plate IV, fig. 1) it is resting on a broad cut surface. It is of irregular shape, but shows one nearly flat surface (on the left of figure) only partially covered with crust (see Medlicott, l. c. p. 34). The other surfaces (as seen on the right of figure) are traversed by bands darker than the rest of the crust. The specific gravity of specimen 48369 is 3·49 as determined by hydrostatic weighing, and that of 51189, 3·48.[1]

Under the microscope, thin sections present characters indistinguishable from that of Daniel's Kuil, and show much nickel-iron and troilite in a crystalline matrix of enstatite, occasionally exhibiting radiating structure. Oldhamite is present in fair amount: in one section a piece of this mineral, orange-red in colour and exhibiting well-marked cubic

[1] The specific gravity is low as compared with Daniel's Kuil, but the Khairpur stones had undergone more oxidation. The method of determination by hydrostatic weighing also gives lower results than that by the pyknometer.

cleavage, measured about 4 mm. in length. As in Daniel's Kuil, graphitic material is present in rings generally surrounding grains of oldhamite, and in one case crossing a chondrule of radiating enstatite. The meteorite is almost precisely similar to Daniel's Kuil and, as shown by the following analyses, belongs like it to the rare Hvittis group.

Chemical Composition.

For the analyses, a fragment weighing about 8 grams of the smallest specimen (48369) was used. By means of a magnetic comb it was divided into an attracted portion weighing 1·8419 grams, and an unattracted portion weighing 6.0431 grams. The results of the analyses are :—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	72·05	—	16·83
Ni	5·54	—	1·29
Co	0·73	—	0·17
Fe	0·96	5·27	4·47
S	0·55	3·01	2·56
Ca	—	0·24	0·19
S	—	0·19	0·15
SiO_2	1·59	52·37	42·64
TiO_2	—	nil	nil
Al_2O_3	—	2·18	1·76
$FeO.Cr_2O_3$	—	0·49	0·39
$FeS.Cr_2S_3$	—	0·36	0·29
Fe_2O_3	—	3·57	2·88
NiO	—	trace	—
CaO	0·98	1·53	1·46
MgO	trace	28·61	23·09
K_2O	—	0·13	0·10
Na_2O	—	0·99	0·80
P_2O_5	—	trace	trace
H_2O	—	0·25	0·20
Graphite	—	0·51	0·41
Insoluble	17·44	—	—
	99·84	99·70	99·68

Again in the analysis of the attracted as in that of Daniel's Kuil occurs a certain amount of apparently free silica. The CaO in the

attracted portion is also difficult to account for; in amount it is about sufficient to form oldhamite with the sulphur, but the idea that this mineral was enclosed in the iron is too uncertain to warrant departure from the usual plan of attributing the sulphur to troilite.

The analysis of the unattracted is the combined result of analyses of the soluble and insoluble constituents of the unattracted, together with separate determinations of the chromium, sulphur, and water, as follows:—

Soluble.			Insoluble.		
SiO_2	...	0·48	SiO_2	...	60·65
Fe_2O_3[1]	...	3·02	TiO_2	...	nil
CaO	...	0·56	Al_2O_3	...	2·55
MgO	...	0·15	Cr_2O_3	...	0·38
NiO	...	trace	FeO	...	0·77
Ca	...	0·24	CaO	...	1·13
S	...	0·19	MgO	...	33·42
Cr_2S_3[2]	...	0·25	K_2O	...	0·15
Fe	...	5·34	Na_2O	...	1·16
S	...	3·05			100·21
C[3]	...	0·51			
H_2O	...	[0·25]			
Insoluble	...	85·57			
		99·61			

The oldhamite was determined from the calcium obtained by digesting the unattracted material in water slightly acidified with acetic acid. The small amount probably does not represent the average in the stone, for in some sections the mineral appears to be fairly plentiful (see p. 18).

The mineral composition deduced from the analyses is as follows:—

$NaAlSi_3O_8$	...	6·85	...	8·25	...	Felspar.
$KAlSi_3O_8$	...	0·56				
$CaAl_2Si_2O_8$	...	0·84				
$FeO.Cr_2O_3$	...	...	...	0·39	...	Chromite.
$FeS.Cr_2S_3$	...	...	...	0·29	...	Daubreelite.

[1] Rrepresents excess of Fe over that required to form FeS: it is considered to be the result of oxidation of the sample analysed, and is reckoned as Fe_2O_3.

[2] Calculated from difference between total Cr and that in the insoluble.

[3] Loss on ignition of insoluble.

$MgSiO_3$	57·64				
$CaSiO_3$	2·67	60·31	...	Enstatite.	
Ca	0·19				
S	0·15	0·34	...	Oldhamite.	
Fe	4·47				
S	2·56	7·03	...	Troilite.	
Fe	16·83				
Ni	1·29	18·29	...	Nickel-iron.	
Co	0·17				
Fe_2O_3	...	2·88			
SiO_2	...	1·51			
H_2O	...	0·20	...	Water.	
C	...	0·41	...	Graphite.	
		99·90			

Specific gravity, 3·49.

The result of the analyses is to show that Khairpur contains oldhamite and consists mainly of a nearly pure enstatite free from iron and a nickel-iron poor in nickel (Fe : Ni=13). It is precisely similar in composition to Daniel's Kuil and like it belongs to the rare Hvittis type of chondritic stone.

The results of the analyses of Cronstad, Daniel's Kuil, and Khairpur indicate generally that in chondritic stones containing large amounts of nickel-iron (over 10 per cent.), that iron is poor in nickel and corresponds to the hexahedrites and nickel-poor octahedrites of the siderites, whereas in stones like Baroti containing from 7–9 per cent. of nickel-iron, that iron is much richer in nickel and corresponds to the nickel-rich ataxites. Moreover, in the stones containing more than 10 per cent. of nickel-iron the magnesium silicates contain a smaller proportion of ferrous oxide, and in the Hvittis type are practically free from iron.

In order to test whether this interrelation between the amount and composition of the nickel-iron and the composition of the ferromagnesium silicates extended in the opposite direction to chondritic stones containing a less amount of nickel-iron than Baroti, it was decided to make a new analysis of the Soko-Banja stone, for the analyses of this and some other stones (Krähenberg, Ngawi, Buschhof, and Makariwa) lent considerable support to the view that in such stones the small amount of iron was

richer in nickel[1] and the ferromagnesium minerals richer in iron. This stone was chosen since there was plenty of material in the British Museum Collection, and the old analysis by S. M. Losanitch showed some discrepancies, for although the stone is stated to contain about 4 per cent. of nickel-iron, the bulk-analysis, as calculated by Wadsworth from the analyses of the soluble and insoluble material, shows practically none.

Soko-Banja.

Descriptions of the phenomena attending the fall of the Soko-Banja meteorite have been given by E. Doll,[2] and by S. M. Losanitch.[3] According to these accounts the meteorite fell about 2 p.m. on October 13, 1877, in the neighbourhood of Soko-Banja, in the district of Alexinatz, Serbia. High up in a clear sky a luminous ball was first observed, from which after a short time proceeded a large white cloud, and twenty-five seconds later three detonations were heard. The stones were seen to fall by peasants working in the fields, and were picked up the same day. Ten stones were found, of which the largest weighed 38 kg. and two others 16 kg. each. The total weight was about 80 kg. The individual stones were scattered over an area of about 12 km. from N. to S. and about 2 km. from E. to W. The path of the meteorite formed with the magnetic meridian an angle of 220° 50′ from N.E. to S.W. and was very steep. The explosion took place at a height of about 7,000 metres.

Physical Characters.

The specimen (51857) in the British Museum from which material was taken for analysis weighs 1,970 grams and is a portion of a much larger stone. As seen in Plate IV, fig. 2, the dull black crust shows some well-defined 'thumb-marks' and patches of the red soil in which the stone fell. The fractured surface is pale grey and shows numerous chondrules perfectly spherical and easily detachable. The structure is somewhat clastic, for besides the chondrules there are many small irregularly-shaped fragments which can also be easily detached from the rather friable matrix; some of these fragments measure as much as 2 cm.

[1] W. Flight (Proc. Roy. Soc., 1881–2, p. 34) more than thirty years ago came to the conclusion that the less the amount of nickel-iron in meteoric stones the richer it was in nickel, but hitherto the idea appears to have met with no general acceptance.

[2] E. Doll, Verh. k.-k. Geol. Reichsanstalt, Wien, 1877, p. 283.

[3] S. M. Losanitch, Ber. Deutsch. Chem. Gesell., 1878, vol. xi. p. 96.

across. Troilite is seen in nodules up to 1 cm. in diameter scattered sparingly through the mass, but the nickel-iron only occurs in small grains scarcely to be distinguished with the naked eye.

Under the microscope, numerous and well-defined chondrules are seen in a crystalline matrix : most are of densely fibrous bronzite, but some show small olivines in good crystals sharply defined in a dark grey, glassy base. Troilite is plentiful in minute grains and also attached to nickel-iron which occurs in rounded grains sparsely distributed. The fragmental material is clearer and more definitely crystalline than the main mass, and contains fewer chondrules. The specific gravity of the stone has been given by Losanitch as 3·502.

Chemical Composition.

A fragment weighing about 15 grams was separated by the magnetic comb into an attracted portion weighing 0·9210 grams and an unattracted portion weighing 13·7830 grams. The results of the analyses are as follows :—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	47·46	0·21	3·17
Ni	15·83	0·07	1·06
Co	1·37	...	0·09
Fe	—	3·33	3·17
S	trace	1·90	1·81
SiO_2	3·93	43·29	41·45
TiO_2	—	0·10	0·10
Al_2O_3	—	1·97	2·12
Cr_2O_3	—	0·38	0·36
FeO	3·60	18·40	17·73
MnO	—	0·05	0·05
CaO	nil	2·02	1·92
MgO	4·90	26·61	25·63
K_2O	—	0·07	0·07
Na_2O	—	0·89	0·85
P_2O_5	—	0·26	0·24
H_2O	—	0·18	0·17
Insoluble	22·73	—	—
	99·82	99·73	99·99

Analysis of a portion of the unattracted soluble in dilute hydrochloric acid gave the following result:—

SiO_2	...	20·29
FeO	...	14·44
CaO	...	0·35
MgO	...	19·26
FeS, &c.[1]	...	5·51
Insoluble	...	40·17
		100·02

The composition of the olivine given by this analysis is approximately $2\frac{1}{2}Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition calculated from the preceding analyses is as as follows:—

$NaAlSi_3O_8$	...	7·21				
$KAlSi_3O_8$	...	0·65	...	9·09	...	Felspar.
$CaAl_2Si_2O_8$	...	1·23				
$FeO . TiO_2$	...	...	...	0·18		
$FeO . Cr_2O_3$	...	...	...	0·45	...	Chromite.
$3Ca_3P_2O_8 . CaO$	...	...	...	0·56	...	Apatite.
$CaSiO_3$	...	2·82				
$FeSiO_3$	...	8·64	...	30·60	...	Bronzite.
$MgSiO_3$	...	19·14				
Fe_2SiO_4	...	18·20				
Mg_2SiO_4	...	31·41	...	49·61	...	Olivine.
Fe	...	3·17				
S	...	1·81	...	4·98	...	Troilite.
Fe	...	3·17				
Ni	...	1·06	...	4·32	...	Nickel-iron.
Co	..	0·09				
H_2O	...	...	...	0·17	...	Water.
				99·96		

The above results confirm the general accuracy of Losanitch's analysis and show that Soko-Banja contains only about 4 per cent. of nickel-iron very rich in nickel (Fe : Ni=3), and olivine and bronzite much richer in iron than in Baroti, the ratio of MgO to FeO in the olivine being about $2\frac{1}{2}$, and in the bronzite 3.

[1] From analysis of unattracted portion.

Conclusion.

As a general result of the analyses of the stones described in this paper, the conclusion is drawn that *in chondritic meteoric stones the less the amount of metallic iron the richer it is in nickel, and the richer in iron are the ferromagnesium minerals.*

The significance of this result with respect to the genetic relationship of meteorites, and the idea that a magma such as gave rise to meteorites of the Hvittis type is the source from which the other types of meteoric stones have been derived by progressive oxidation of the nickel-iron, are considered in the following paper.

Explanation of Plates I–IV.

Plate I, fig. 1.—Meteoric stone which fell at Launton, Bicester, Oxfordshire, on February 15, 1830. Weight 998 grams. Reg. No. B.M. 77528. ($\times \frac{2}{3}$.)

—— fig. 2.—Meteoric stones collected in 1904 in the Warbreccan run, 40 miles west of Windorah, central Queensland. B.M. 1905, 377–379. ($\times \frac{1}{7}$.)

Plate II, figs. 1 and 2.—Two views of the largest of the Warbreccan meteoric stones. Weight 31,610 grams (about 69 lb.). B.M. 1905, 377. ($\times \frac{1}{6}$.)

—— figs. 3 and 4.—Two views of the Warbreccan meteoric stone, weighing 29,100 grams (about 64 lb.). B.M. 1905, 378. ($\times \frac{1}{6}$.)

Plate III, fig. 1.—Fragment, weighing 285 grams, of one of the meteoric stones which fell at Cronstad, Orange Free State, South Africa, on November 19, 1877. B.M. 52149. ($\times \frac{1}{2}$.)

—— fig. 2.—Another of the Cronstad meteoric stones, weight 882 grams. B.M. 55428. ($\times \frac{1}{2}$.)

—— fig. 3.—Plaster cast of the meteoric stone which fell at Daniel's Kuil, Griqualand West, South Africa, on March 20, 1868. B.M. 65884. ($\times \frac{1}{2}$.)

—— fig. 4.—Three fragments (total weight 431 grams) fitted together, and reconstructing one-half of the Daniel's Kuil meteoric stone. B.M. 42388, 42502, 42503. ($\times \frac{1}{2}$.)

Plate IV, fig. 1.—Fragment, weighing 3,010 grams, of one of the meteoric stones which fell at Khairpur, near Bhawalpur, Punjab, India, on September 23, 1873. B.M. 51366. ($\times \frac{2}{3}$.)

—— fig. 2.—Fragment, weighing 1,970 grams, of one of the meteoric stones which fell at Soko-Banja, Alexinatz, Serbia, on October 13, 1877. B.M. 51857. ($\times \frac{2}{3}$.)

On the genetic relationship and classification of Meteorites.[1]

By G. T. Prior, M.A., D.Sc., F.R.S.

Keeper of the Mineral Department of the British Museum.

[Read January 18 and June 20, 1916.]

In a previous paper[2] attention was drawn to the close similarity in mineral and chemical composition of chondritic meteoric stones. In the case of about forty chondrites it was shown that, apart from variations in the amount of nickel-iron, not only are the constituent minerals present in very similar amounts, but their chemical compositions vary to no very great extent. In that paper sufficient importance was not attached to the variations in the amount of nickel-iron. The chemical investigations of the meteorites described in the paper immediately preceding show that this variation is of much greater significance than had been supposed. It was found that a progressive change in the chemical composition of the nickel-iron and of the magnesium silicates could be traced from chondritic stones like Daniel's Kuil containing over 20 per cent. of nickel-iron to those like Soko-Banja containing only small amounts. The analyses in fact indicate that *the less the amount of nickel-iron in chondritic stones, the richer it is in nickel and the richer in iron are the magnesium silicates.*

This interrelation between the amount and chemical composition of the nickel-iron and the chemical composition of the magnesium silicates

[1] Communicated by permission of the Trustees of the British Museum.

[2] G. T. Prior, 'On the remarkable similarity in chemical and mineral composition of chondritic meteoric stones.' Mineralogical Magazine, 1913, vol. xvii, pp. 33–38.

can be seen at a glance in the following table embodying the results of the analyses of the meteorites Daniel's Kuil, Cronstad, Baroti, and Soko-Banja, which contain, in order, decreasing amounts of nickel-iron:—

Type.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in olivine.	Ratio of MgO to FeO in pyroxene.	Ratio of total Fe atoms to Mg atoms.
(1) Daniel's Kuil	25½	13	—	8	1·03
(2) Cronstad	18½	11	4	6	1·22
(3) Baroti	9	6½	8	4	1·46
(4) Soko-Banja	4	8	2½	8	1·80

As seen in the lists on pp. 28–31, most of the previously published analyses of chondritic stones supply convincing evidence in support of this interrelation.

The Classification of Chondrites.

Although the relationship indicated above is probably a perfectly continuous one, for purposes of classification it is convenient to make somewhat arbitrary divisions. It is proposed, therefore, to divide chondritic stones into four groups corresponding to the four types: (1) Daniel's Kuil (Hvittis), (2) Cronstad, (3) Baroti, and (4) Soko-Banja.

Group 1. *Daniel's Kuil* (*Hvittis*) *Type.*

In this group the structure is crystalline; chondrules are few and of ill-defined shape; a nickel-poor (Fe : Ni greater than 10) nickel-iron is in large amount (20 per cent. and over); the magnesium silicate is a nearly pure enstatite ($MgSiO_3$), practically free from iron and containing little or no lime; the felspar is near to oligoclase; and the sulphide of calcium, oldhamite, is a characteristic accessory constituent.

The following list gives for the four members of Group 1 at present known the percentage of nickel-iron, the ratio of Fe to Ni in the nickel-iron, the ratio of MgO to FeO in the magnesium silicates, the symbol in the Rose-Tschermak-Brezina classification, and the name of the analyst and date of publication:—

Group 1. Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg silicates.	Symbol.	Analyst and date.
Daniel's Kuil (type)	25½	13	8 8	Ck	G. T. Prior, 1916.
Hvittis	21	10	8 8	Ck	L. H. Borgström, 1903.
Khairpur	18	13	8 8	Ck	G. T. Prior, 1916.
Pillistfer	21½	10	30	Ck	C. Grewingk and C. Schmidt, 1863.

To this list should probably be added St. Marks,[1] and more doubtfully Indarch,[2] for both contain oldhamite, in both pyroxene constitutes the main mass of the magnesium silicates, and in St. Marks this is an enstatite almost free from iron.

Group 2. *Cronstad Type.*

In this group chondrules are more plentiful and more sharply defined; a nickel-iron, poor in nickel (Fe : Ni generally as high as 10), is in large amount (over 10 per cent.); olivine is present as well as pyroxene, both containing iron in such amount that the ratio of MgO : FeO is generally from 4–6; the pyroxene is mainly bronzite, but a lime-poor monoclinic pyroxene[3] generally accompanies it in small amount; the felspar is oligoclase.

The following is a list of chondritic stones which the data, drawn from the published analyses,[4] indicate belong to this group:—

[1] E. Cohen, Ann. South African Museum, 1906, vol. v, p. 1.

[2] G. P. Merrill, Proc. U. S. Nat. Museum, 1915, vol. xlix, p. 109.

[3] W. Wahl, 'Die Enstatitaugite.' Min. Petr. Mitt., 1907, vol. xxvi, p. 1.

[4] In the following lists are included, besides other more recent analyses, all those quoted by O. C. Farrington in 'Analyses of Stone Meteorites'. Field Museum of Natural History, 1911, Publication 151, Geol. Series, vol. iii, No. 9. The original references have been consulted, for in Farrington's list it is not always possible to determine whether the iron for the sulphur is to be taken from Fe or FeO. Where the chemical composition of the olivine and bronzite have been determined, the ratio of MgO to FeO has been calculated from them. The numbers in brackets placed in some cases after this ratio is the ratio for the insoluble alone, for, when the separation of the metallic iron has been imperfect, more reliance can be placed upon this ratio than upon that for the soluble.

Group 2. Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.	Symbol.	Analyst and date.
Cronstad (type)	18½	11	4½	Cg	G. T. Prior, 1916.
Allegan	23	12	5	Cco	H. N. Stokes, 1900.
Baldohn	18	12	3½	Cc	E. Johanson, 1892.
Beaver Creek	17	10	4½	Cck	W. F. Hillebrand, 1894.
Blansko	17	15	3½ (5)	Cga	J. J. Berzelius, 1834.
Cabarrus County	13½	14	5	—	J. E. Whitfield, 1916.
Cape Girardeau	18	12	4½	Cc	S. L. Penfield, 1886.
Carcote	10	10	3 (4)	Ck	W. Will, 1889.
Cléguérec	20	13	4	Ck	F. Pisani, 1869.
Cullison	19	10	5	—	J. E. Whitfield, 1913.
Dundrum	20	18	5	Ck	S. Haughton, 1866.
Estacado	16	9	3½ (4½)	Ckb	J. M. Davison, 1906.
Gnarrenburg[1]	23	12	9	Ccb	F. Wöhler, 1856.
Gopalpur	20	11	3 (4)	Cc	A. Exner, 1872.
Hedjaz	11	9	4	—	F. Pisani, 1912.
Hessle	19	8	4	Cc	G. Lindström, 1870.
Khetri	17	18½	4½	Cgb	D. Waldie, 1869.
Klein-Wenden[1]	23	9	7	Ck	C. Rammelsberg, 1844.
Linn County	10½	9	3½	Cwa	C. Rammelsberg, 1870.
Linum[1]	13	22	32	Cw	A. Lindner, 1904.
Lixna	15	8	4 (5)	Cga	A. Kuhlberg, 1867.
Molina[1]	15	10	10 (75)	Cw	S. Meunier, 1869.
Mount Browne	18	9	5	—	H. P. White, 1902.
Nash County	14	11	4	Cgb	J. L. Smith, 1875.
Ogi	17	10	5	Cw	T. Shimidzu, 1882.
Orvinio	21	9	5	Co	L. Sipöcz, 1875.
Pultusk	10	13	3½ (4½)	Cga	G. vom Rath, 1869.
Rochester	10	17	3½ (4)	Cc	J. L. Smith, 1877.
Searsmont	14	10	3½	Cc	J. L. Smith, 1871.
Sevrukovo	16½	8	4½	Cs	A. Eberhard, 1882.
Ställdalen	18	11	4½	Cga	G. Lindström, 1877.
Stavropol[2]	10	—	4 (3½)	Ck	H. Abich, 1860.
Utah	17	11	4 (5)	—	S. L. Penfield, 1886.
Winnebago County	19	15	4½	Ccb	L. G. Eakins, 1890.

[1] Doubtful; if correct, these analyses, in which the ratio MgO : FeO is so high, suggest a passage to Group 1. In the case of Klein-Wenden, as in some others of his analyses, Rammelsberg appears to have rather over-corrected for the NiO in the unattracted part.

[2] The numbers given depend on Abich's statement that the stone contains over 10 per cent. of nickel-iron, instead of the much lower amount indicated by the bulk-analysis.

Group 3. *Baroti Type.*

Chondrites of this group contain from 6–10 per cent. of nickel-iron, rich in nickel (Fe : Ni generally from 6–8); the ferromagnesium minerals are olivine and pyroxene in which the ratio of MgO to FeO is generally 3–4; the pyroxene is mainly bronzite but, as in group 2, a lime-poor monoclinic pyroxene may also be present; the felspar or glass has the composition of oligoclase.

The following is a list of chondrites which the published analyses indicate belong to this group:—

Group 3. Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.	Symbol.	Analyst and date.
Baroti (type)	9	6½	3½	Cw	G. T. Prior, 1913.
Ausson	8	7	3	Cc	E. P. Harris, 1859.
Bjurböle	7	8	3½	Cca	W. Ramsay & L. H. Borgström, 1902.
Chantonnay	8	6	3½	Cgb	C. Rammelsberg, 1870.
Coon Butte	8½	8	4 (3)	Cib	J. W. Mallet, 1906.
Farmington	7	7	3½	Cs	L. G. Eakins, 1892.
Launton	8½	6	3½	Cia	G. T. Prior, 1916.
Lesves	8	7½	3	Cw	A. F. Renard, 1896.
Meuselbach	8	6	3 (3½)	Ccka	G. Linck, 1899.
Mezö-Madaras	9	5	3 (3)	Cgb	C. Rammelsberg, 1871.
Modoc	7	9½	3½	Cwa	W. Tassin, 1906.
Muddoor	9	7	3	Cc	F. Crook, 1868.
Parnallee	6½	5	4	Cga	E. Pfeiffer, 1863.
Pickens County[1]	9	7	3	—	E. Everhart, 1909.
Rakovka	7	4	3½	Ci	P. Grigorieux, 1880.
Richmond	8	7	3½ (3)	Cck	C. Rammelsberg, 1870.
St. Christophe	9	5	3½	Cg	A. Lacroix, 1906.
St. Denis-Westrem	8	6	3½	Cca	C. Klement, 1886.
St. Michel	8½	7	3½	Cw	L. H. Borgström, 1912.
Stewart County	7	7	3½ (2½)	Cck	J. L. Smith, 1870.
Tourinnes-la-Grosse	8½	5½	3	Cw	F. Pisani, 1864.
Utrecht	9	7	3	Cca	E. H. von Baumhauer, 1845.
Warbreccan	7	6	3½	Cwa	G. T. Prior, 1916.
Wittekrantz	8	7	3½	Cw	G. T. Prior, 1913.
Zomba	8½	7	3½	Cw	L. Fletcher, 1901.

[1] Doubtful, as it contains nearly 11 per cent. of Fe_2O_3.

Group 4. Soko-Banja Type.

In this group the nickel-iron is in small amount (less than 6 per cent.) and is very rich in nickel (Fe : Ni less than 5); the ferromagnesium minerals are olivine and pyroxene as in groups 2 and 3 but are still richer in iron, the ratio MgO : FeO being less than 3; the felspar is oligoclase.

The published analyses indicate that the following chondrites belong to this group:—

Group 4. Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.	Symbol.	Analyst and date.
Soko-Banja (type)	4	3	2½	Cc	G. T. Prior, 1916.
Albareto	5	6	2	Cc	P. Maissen, 1880.
Alfianello	7	5	2½	Ci	P. Maissen, 1884.
Bachmut [1]	6½	4	3 (4½)	Cw	A. Kuhlberg, 1867.
Binda	½	—	2	—	J. C. H. Mingaye, 1913.
Bluff [2]	5½	5	2½	Ck	J. E. Whitfield, 1888.
Buschhof	5	2	2½	Cwa	C. Grewingk & C. Schmidt, 1864.
Cold Bokkeveld	0	—	1	K	E. P. Harris, 1859.
Eli Elwah [3]	—	—	2	C	A. Liversidge, 1908.
Ergheo	1	3	3	Ckb	G. Boeris, 1898.
Honolulu [1]	4	1½	2 (4½)	Cwa	A. Kuhlberg, 1867.
Kaba	4	2½	1½	K	F. Wöhler, 1858.
Knyahinya	5	4	2½	Cg	E. H. von Baumhauer, 1872
Krähenberg	3½	5	2	Cho	G. vom Rath, 1869.
Long Island [4]	3	4	3 (9)	Cia	H. W. Nichols, 1902.
Makariwa	5	4	3	Cgb	L. Fletcher, 1894.
Mauerkirchen [5]	4	4	2	Cw	F. Crook, 1868.
Mocs	5	3	1½	Cwa	F. Koch, 1883.
Nerft [1]	6	4	3 (4½)	Cia	A. Kuhlberg, 1869.
Ngawi	3	5	2	Ccn	E. H. von Baumhauer, 1884.
Orgueil [6]	0	—	2	K	F. Pisani, 1864.
Ornans [7]	2	—	2 (5)	Cco	F. Pisani, 1868.
Saline Township	6	4	2	Cck	H. W. Nichols & E. W. Tillotson, 1911.
Uden	2	—	1½	Cwb	E. H. von Baumhauer & F. Seelheim, 1862.
Waconda	5	7	2	Ccb	J. L. Smith, 1877.
Zavid	0	—	2	Cia	C. Hödlmoser, 1901.

[1] These possibly belong to Group 3, for the MgO : FeO ratio for the insoluble is as high as 4½, and the specific gravities of the stones are all over 3·5, which

[Foot-notes continued on p. 32.]

The analyses from which the data given in the preceding lists have been calculated date back as far as 1834 and are doubtless of very unequal value especially as regards the determination of the nickel-iron and its content of nickel. It is only to be expected, therefore, that, where three conditions have to be satisfied, some analyses will present discrepancies which make it difficult to fix with certainty the groups to which the stones belong. In order to test by means of the older analyses the principles suggested by the writer's own work, it was decided, as the most satisfactory proceeding, to consider every analysis in Farrington's pamphlet, rather than to make a selection of those which might be regarded as the most accurate. In the preparation of such a list as Farrington's the work of choosing the most satisfactory must have been a difficult one. It is not surprising therefore to find (see footnotes) that it includes many which a critical examination suggests are inaccurate or incomplete, and omits some which are beyond reproach.[8]

The following list of the remaining chondritic stones referred to in Farrington's pamphlet contains those of which the analyses appear to be most at variance with the principles which the preceding lists serve to support :—

suggests a somewhat higher percentage of nickel-iron than that given in the analyses.

[2] Doubtful, for the soluble contains nearly 3 per cent. and the insoluble nearly 2 per cent. of NiO, indicating that the separation *by means of iodine* of the metal was imperfect.

[3] Doubtful, as the analysis was incomplete, the nickel-iron not being determined. It possibly belongs to Group 3.

[4] Doubtful, as it is supposed to contain 10 per cent. of limonite ; the ratio for the bronzite is so high owing to the large amount of FeO required for the extraordinarily high percentage of chromite (nearly 10 per cent.).

[5] Doubtful : on Crook's analyses, see G. Tschermak, Sitzber. Wien. Akad., 1872, vol. lxv, p. 134.

[6] Doubtful, as it contains nearly 8 per cent. of Fe_2O_3.

[7] Doubtful, owing to high MgO : FeO ratio for the insoluble and the presence of nearly 3 per cent. of NiO in the soluble. It possibly belongs to Group 2, like Allegan, which belongs to the same class (Cco), as does also Warrenton, which so closely resembles Ornans in external appearance.

[8] The omission of some of the most detailed and accurate analyses of meteoric stones we possess, such as those of Zomba and Makariwa by L. Fletcher, was due probably to the results being given as analyses of the individual constituents and not as bulk-analyses.

Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.	Symbol.	Probable Group.	Analyst and date.
Adare	19	6	3½	Cga	3	R. Apjohn, 1874.
Amana	12	5	1½	Cgb	4	C. W. Gümbel & A. Schwager, 1875.
,,	12½	8	1⅔	—	—	J. L. Smith, 1875.
Borkut[1]	22	8	3 (2½)	Cc	3	J. Nuricsany, 1856.
Chandakapur	6	10	2 (4½)	Cib	3	H. E. Clarke, 1910.
Château-Renard	8½	4	1 (2)	Cia	4	A. Dufrénoy, 1841.
Cynthiana	6	11	3 (4)	Cg	3	J. L. Smith, 1877.
Dhurmsala	8	4	4½	Ci	4	S. Haughton, 1866.
Drake Creek	11½	6½	3½	Cwa	3	E. H. von Baumhauer, 1845.
Ensisheim	9	7	2½	Ckb	—	F. Crook, 1868.
Felix	3	7	1½ (16)	Kc	—	P. Fireman, 1901.
Gnadenfrei	26	5½	2 (2½)	Cc	4	J. G. Galle & A. von Lasaulx, 1879.
Hendersonville	2½	11	4 (5)	Cc	2	W. Tassin, 1907.
Heredia	26	15	2 (2½)	Ccb	—	I. Domeyko, 1859.
Jerome	4	9	1 (5)	Cck	2	H. S. Washington, 1898.
Kakowa	8	6	2 (∞)	Cga	—	E. P. Harris, 1859.
Lundsgård	12	5	3½	Cw	3	O. Nordenskjöld, 1891.
Middlesbrough	9	3	1½ (1)	Cw	4	W. Flight, 1882.
New Concord	10½	7	1½	Cia	—	J. L. Smith, 1861.
Shelburne	8	10	3	Cg	3	L. H. Borgström, 1904.
Shytal	10	6	2	Cib	3	T. Hein, 1866.
Tadjera	8	11	3 (½)	Ct	—	S. Meunier, 1868.
Takenouchi	13	7	2½	Ck	—	A. Lindner, 1904.
Tieschitz	8½	5½	2	Cc	4	J. Habermann, 1879.
Travis County	2	8	4 (5)	Cs	2	L. G. Eakins, 1891.
Warrenton	2	9	3 (4)	Cco	2	J. L. Smith, 1877.

In ten of the stones in this list (viz. Adare, Amana, Château-Renard, Drake Creek, Gnadenfrei, Hendersonville, Lundsgård, Middlesbrough, Tieschitz, and Travis County) the discrepancy occurs only in the amount of nickel-iron. In some cases this may be accounted for by variations in the amount of nickel-iron in different parts of the stone, the portion analysed not being a fair sample. This appears to have been the case with Amana, for Lawrence Smith remarks that 'the specimen analysed had a vein running through it which was much richer in iron than the mass to which it belonged'. Hendersonville and Jerome show discrepancies owing to their having been much oxidized. In the case of Jerome, Felix, and Warrenton, also, the presence of from 1–3 per cent. of NiO in

[1] Wadsworth's calculation of the bulk-analysis, as quoted by Farrington, is not in agreement with the details of the analyses.

the soluble suggests imperfect separation of the nickel-iron. In Chandakapur the nickel has probably been under-estimated, since the separation from iron was by means of ammonia. As regards Dhurmsala, examination of specimens and sections in the British Museum Collection suggests that the metallic iron, as well as the sulphur and chromium, have been over-estimated.

Classification of Non-chondritic Stones.

Turning now to the non-chondritic meteoric stones, we should expect, if the same principle which governs the variation in chemical composition of chondritic stones applies also to them, that those containing large amounts of nickel-iron, like the siderolites, would have that iron poor in nickel and their ferromagnesium minerals correspondingly poor in iron, whereas those with little or no iron should have that iron rich in nickel and their ferromagnesium minerals rich in iron. The published analyses of these stones, data from which are given in the following lists, show that this is generally the case.

Achondrites containing large amounts of nickel-iron.

Taking first the case of the non-chondritic stones containing large amounts of nickel-iron, the following list gives the ratio of Fe to Ni in the nickel-iron, and the ratio of MgO to FeO in the ferromagnesium silicates for various siderolites (including under that name also lithosiderites):—

Name.	Ratio of Fe to Ni.	Ratio of MgO to FeO in olivine.	Ratio of MgO to FeO in pyroxene.	Class.	Analyst and date.
Admire	15	7	—	Pallasite	W. Tassin, 1902.
Brahin	11	7	—	,,	A. A. Inostranzeff, 1869.
Brenham Township	9	8	—	,,	L. G. Eakins, 1890.
Eagle Station	5	4	—	,,	J. B. Mackintosh, 1887.
Imilac	9	7	—	,,	F. v. Kobell, 1851.
Marjalahti	12	7	—	,,	L. H. Borgström, 1903.
Mount Dyrring	19	7	—	,,	J. C. H. Mingaye, 1904.
Mount Vernon	6	4	—	,,	W. Tassin, 1905.
Pallas Iron	9	6	—	,,	J. E. Whitfield, 1916.
South Bend	10	—	—	,,	H. W. Nichols, 1906.
Breitenbach	9	—	5	Siderophyre	C. Winkler, 1878.
Estherville	13	6	2	Mesosiderite	J. L. Smith, 1880.

Name (*cont.*).	Ratio of Fe to Ni.	Ratio of MgO to FeO in olivine.	Ratio of MgO to FeO in pyroxene.	Class.	Analyst and date.
Mainholz	10	3	3	Mesosiderite	F. Wöhler, 1857.
Llano del Inca	10	$\frac{1}{13}$	2	,,	L. G. Eakins, 1890.
Taney County	$12\frac{1}{2}$	7	3	,,	J. L. Smith, 1865.
Morristown	12	$\frac{1}{2}$	3	Grahamite	L. G. Eakins, 1893.
Powder Mill Creek	7	$\frac{1}{2}$	4	,,	J. E. Whitfield, 1887.
Lodran	7	7	5	Lodranite	G. Tschermak, 1870.

The list shows that, on the whole, the siderolites, in the poorness in nickel of the nickel-iron and the poorness in iron of the ferromagnesium minerals, correspond to Group 2 (Cronstad type) of chondritic stones. In the pallasites, with the exception of Mount Vernon and Eagle Station, the ratio of MgO to FeO is remarkably constant at about 7. The grahamites (including some mesosiderites), containing a felspar near to anorthite, appear to have relations with the eucrites, since they are richer in lime and alumina than most chondritic stones (see p. 37). Further analyses, however, of the individual minerals of these felspar-bearing siderolites are needed before their place can be definitely fixed. Where this has been done, as in the case of Estherville and Taney County by Lawrence Smith, the ratio of the MgO to FeO for the olivine was found to be about 7 as in the pallasites, and that of the pyroxene about 3. In other cases (e.g. Morristown and Llano del Inca) where the separation has been made into parts soluble and insoluble in acids, although the ratio for the pyroxene is still about 3, that of the olivine sinks to less than unity; possibly owing to admixture with metallic iron not separated by the magnet, for the soluble in Morristown contains over 1 per cent. of NiO, and that of Llano del Inca nearly 3 per cent.

Achondrites containing little or no nickel-iron.

In these non-chondritic stones (with the exception of the bustites and ureilites) it is found, according to expectation, that the ferromagnesium minerals are rich in iron, and the small amount of nickel-iron, when present, is correspondingly very rich in nickel. The following list gives the percentage of nickel-iron, the ratio of Fe to Ni in this iron, and the

ratio of MgO to FeO in the ferromagnesium silicates for most of these stones:—

Name.	Percentage of nickel-iron.	Ratio of Fe to Ni in nickel-iron.	Ratio of MgO to FeO in Mg-silicates.	Class.	Analyst and date.
Ibbenbühren	—	—	2½	Chladnite (Diogenite)	G. vom Rath, 1872.
Manegaum	—	—	2	,,	N. S. Maskelyne & W. Flight, 1870.
Shalka	—	—	2	,,	N. S. Maskelyne & W. Flight, 1871.
Chassigny	—	—	2	Chassignite	A. Damour, 1862.
Jelica	1½	2	2	Amphoterite	S. M. Losanitch, 188
Manbhoom	2	1½	2½	,,	H. von Foullon, 188
Bandong	3	2	1	Rodite	— Vlaanderen, 1872.
Roda	—	—	2½	,,	F. Pisani, 1874.
Vavilovka	3	2	2½	,,	P. Melikov, 1893.
Angra dos Reis	—	—	2½	Angrite	E. Ludwig & G. Tschermak, 1909.
El Nakhla	—	—	1	Nakhlite	G. T. Prior, 1911.
Frankfort	—	—	2	Howardite	G. J. Brush & W. J. Minter, 1869.
Mässing	—	—	1	,,	A. Schwager, 1878.
Petersburg	—	—	1	,,	J. L. Smith, 1861.
Constantinople	—	—	⅓	Eucrite	G. Tschermak, 1872.
Juvinas	—	—	⅓	,,	J. E. Whitfield, 1916
Peramiho	—	—	⅓	,,	E. Ludwig, 1903.
Stannern	—	—	⅓	,,	C. Rammelsberg, 185
Sherghotty	—	—	⅓	Sherghottite	E. Lumpe, 1871.
Bustee	—	24	8	Bustite	N. S. Maskelyne, 187
Bishopville	—	—	8	,,	J. L. Smith, 1864.
Alatyr (Novo-Urei)	5½	26	Olivine 5 / Pyroxene 8	Ureilite	M. Jerofejeff & P. Latschinoff, 1888.
Goalpara	8½	—	Olivine 4 / Pyroxene 12	,,	N. Teclu, 1870.

As seen in this list, the chladnites (diogenites), chassignites, amphoterites, and rodites have a ratio of MgO to FeO of 2 to 2½ and a nickel-iron, when present, extremely rich in nickel. Felspar when present, as e. g. in Jelica and Manbhoom,[1] is oligoclase and not anorthite. In chemical composition therefore these stones correspond to Group 4 (Soko-Banja type) of chondritic stones.

The angrites, nakhlites, howardites, eucrites, and sherghottites, besides

[1] H. Michel, 'Plagioklase der Meteoriten.' Min. Petr. Mitt., 1913, vol. xxxii, p. 170.

having for the most part ferromagnesium silicates still richer in iron, are richer in lime, and (with the exception of El Nakhla) also in alumina, than chondritic stones generally. These chemical characters manifest themselves in most of the stones by a fairly high content of felspar which is near to anorthite instead of to the oligoclase of chondritic stones, and also in all of them by an increased amount of monoclinic pyroxene, which in the case of the eucrites is the enstatite-augite of Wahl (see p. 28), of small optic axial angle and poor in lime as compared with most terrestrial augites, but containing more than the orthorhombic pyroxenes of the chondrites. In chemical characters, therefore, these stones extend rather beyond the limits of the Soko-Banja group and are not at present represented with certainty amongst chondritic stones, for the so-called howardite-chondrites present no very striking resemblance to howardites under the microscope, and chemically appear to belong mostly to the Soko-Banja group.

Now to the increase of ferrous oxide in the ferromagnesium minerals in stones containing little or no nickel-iron, there are two notable exceptions, viz., the bustites (Bustee, Aubres, and Bishopville), and the ureilites (Alatyr (Novo-Urei), Dyalpur and Goalpara), but these appear to be, *par excellence*, exceptions which prove the rule.

Bustites in the character of their pyroxenic and felspathic constituents differ essentially from the chladnites (diogenites), Shalka, Manegaum, and Ibbenbühren, with which one of them (Bishopville) has hitherto been confused. They consist mainly of a nearly pure enstatite practically free from iron, with oldhamite and an acid plagioclase felspar (near to oligoclase) instead of anorthite, as accessory constituents. Examination of specimens in the British Museum Collection shows that Bustee and Aubres only differ from Bishopville in being rather more clastic, and Bustee also in containing, but for the most part only in the neighbourhood of the nodule rich in oldhamite, a monoclinic pyroxene, rich in lime, and nearly free from iron. Of the two published analyses of Bustee, the one by Dancer, which is very similar to that of Bishopville, probably represents more closely the chemical composition of the main mass of the stone than that of Maskelyne which was made on exceptional material from the neighbourhood of the oldhamite nodule. Although the name 'chladnite' was originally applied to Bishopville, it has become so associated in the Rose-Tschermak classification, as modified by Brezina, with the very different stones, the diogenites of Tschermak, Shalka, Manegaum, and Ibbenbühren, that it may be advisable to retain

it for them, while Bishopville is included with Bustee and Aubres in the bustite class.[1]

Except that they contain so little nickel-iron, bustites, in chemical and mineral composition, are precisely similar to the Daniel's Kuil (Hvittis) type of chondritic stone, for in both oldhamite occurs in fair amount, the nickel-iron (as seen from Maskelyne's analysis) is very poor in nickel, and the enstatite and felspar are similar in chemical composition. Bustites probably separated from the same magma which gave rise to Group 1 of chondritic stones, but under more deep-seated conditions which allowed of a partial segregation of the nickel-iron.

The ureilites consist of a coarsely crystalline aggregate of olivine and monoclinic pyroxene cemented together by a film of nickel-iron and carbonaceous matter. As already pointed out by Wahl,[2] they are not chondritic, but in structure are very similar to the pallasites, the nickel-iron although in small amount forming a similar sort of mesh round the other constituents. The analyses show that the iron is poor in nickel and the ferromagnesium silicates correspondingly poor in iron, the ratio of MgO to FeO for the olivine being about 4–5, and for the pyroxene from 8–12. In spite of their poorness in iron, the ureilites therefore are similar in general composition to Lodran, and correspond to Group 2 (Cronstad type) of chondritic stones, just as the bustites do to Group 1.

The Genetic Relationship of Meteorites.

As pointed out by L. Fletcher,[3] the general similarity of structure and chemical composition and the almost universal presence of nickel-iron suggest a common source for all meteorites. As regards the chondritic stones, the published analyses show that for stones of all four groups the percentage of magnesia varies within only narrow limits. The variations in the amount of ferrous oxide, on the other hand, are considerable, for a stone like Daniel's Kuil belonging to Group 1 contains practically none, whereas stones of the other Groups 2–4 have ferromagnesium silicates increasingly rich in ferrous oxide. This distinction between the groups however becomes almost evanescent when, instead

[1] An alternative plan would be to retain the name Chladnite for Bishopville as a stone consisting mainly of pure enstatite without diopside, and to revive Tschermak's name of diogenite for the bronzite stones, Shalka, Manegaum, and Ibbenbühren.

[2] W. Wahl, Min. Petr. Mitt., 1907, vol. xxvi, p. 90.

[3] Sir L. Fletcher, 'An Introduction to the Study of Meteorites' (British Museum Guide-Book), eleventh edit., 1914, p. 50.

of oxides, atoms are considered. A. E. Nordenskiöld[1] many years ago, and W. Wahl[2] more recently, have shown in the case of several chondritic stones that the atomic composition is very similar, and the latter has drawn the conclusion that the difference between the enstatite-chondrite, Hvittis, and the other chondrites depends only upon the different amounts of oxygen the stones contain. If, in the case of the four type specimens of chondritic stones, the total Mg and Fe atoms be compared instead of only the oxides, the ratio of Mg to Fe shows much less variation than might be expected from the differences in the amount of nickel-iron. As seen in the table on p. 27, for Daniel's Kuil containing 25 per cent. of nickel-iron this ratio is about 1, and for Soko-Banja containing only 4, it is about 1·8. This is a direct result of the interrelationship between the amount and composition of the nickel-iron and the amount of oxide of iron in the magnesium silicates which we have sought in the preceding pages to establish, not only for the chondrites but for meteoric stones generally. It leads at once to the conclusion *that all meteorites have had a common origin from a single magma which is most nearly represented by that which gave rise to the Bustee and the Daniel's Kuil* (*Hvittis*) *types of meteoric stone, and that from this magma all other types have been produced by progressive oxidation of the nickeliferous iron.*

In a magma such as would produce stones of the Daniel's Kuil type the amount of oxygen was sufficient to form oxides with the elements silicon, magnesium, aluminium, sodium, but only partially with calcium and chromium,[3] and scarcely at all with iron. No chemical action therefore was possible which could lead to the production of iron-bearing pyroxenes or of more basic ferriferous olivines. As soon, however, as the magma came under the further influence of oxidizing agents, some of the iron would also be converted into oxide, and a reaction would then be possible by which part of the magnesium silicate would be reduced to a ferriferous olivine, and part converted into a bronzite. In this reaction the nickel took no part, for the ferromagnesium minerals of chondritic stones contain practically no oxide of nickel.[4] Consequently,

[1] A. E. Nordenskiöld, Geol. Fören. Förh. Stockholm, 1878, vol. iv, p. 56.

[2] W. Wahl, 'Beiträge zur Chemie der Meteoriten.' Zeit. Anorg. Chemie, 1910, vol. lxix, p. 67.

[3] Part of the Ca and Cr are in the form of sulphides, oldhamite and daubreelite.

[4] This fact, which has given rise to much comment, has been explained by Wahl (l. c. p. 70) as due to the lower heat of production of oxide of nickel as compared with that of oxide of iron.

the residual iron, according to the degree to which the oxidation was carried, would become progressively more and more enriched in nickel. The production in this way of the particular olivine and bronzite and the nickel-rich iron of Soko-Banja from a magma having the composition of Daniel's Kuil may be represented approximately by the following equation :—

$$\underset{\text{Enstatite}}{19\ MgSiO_3} + \underset{\text{Nickel-iron}}{9\ (Fe + \tfrac{1}{13}\ Ni)} + \underset{\text{Oxygen}}{70}$$
$$= \underset{\text{Olivine}}{2\ (5\ MgO.2\ FeO.3\tfrac{1}{2}\ SiO_2)} + \underset{\text{Bronzite}}{3\ (3\ MgO.FeO.4\ SiO_2)} + \underset{\text{Nickel-iron}}{2\ (Fe + \tfrac{9}{26}\ Ni)}.$$

On the left in this equation the proportion by weight of the enstatite and nickel-poor nickel-iron is about the same as in Daniel's Kuil, and on the right the relative amounts and chemical composition of the olivine and bronzite are about what they are in Soko-Banja, and the nickel-iron is considerably reduced in amount and proportionately enriched in nickel.

It is just conceivable that to some such action as this we must look for the explanation of the formation of chondrules. In the Daniel's Kuil (Hvittis) type chondrules are of rare occurrence and consist almost solely of fibrous pyroxene. If, as suggested by Wahl (l. c. p. 92), chondritic stones were produced under surface conditions like terrestrial volcanic tuffs, it may be that the oxidation of the nickel-iron, with the resultant production of the olivine and bronzite, was of such a violent nature that drops were thrown out in a hot and rarefied atmosphere[1] and consolidated sufficiently slowly to form the crystalline chondrules.

Meteorites and the Earth's interior.

Although no very general support has been given to Sir Robert Ball's[2] suggestion that meteorites falling upon the earth from outer space are only returning to their original home from which they were ejected at an early stage of its history when the moon was separated, there is a widely accepted idea that the earth's interior is composed of material very similar to meteorites. In accordance with the genetic relationship of meteorites suggested above, the earth's core may be regarded as consisting mainly of iron, with other metals, principally Ni, Mg, Ca,

[1] L. H. Borgström, 'Der Meteorit von St. Michel.' Bull. Comm. Géol. Finlande, 1912, No. 34, p. 38.

[2] Sir Robert Ball, 'Speculations on the Source of Meteorites.' Nature, 1879, vol. xix, p. 498.

Na, Al, and Cr, and non-metals, principally Si, S, and C, by the progressive oxidation of which the more superficial formations of the earth's crust have resulted. Above this core it may be imagined is an oxidized zone in which the Mg, Si, Na, Al, and Ca occur more and more in the form of oxides, but the iron and nickel are still in the metallic state. The upper part of such a zone would correspond to a magma such as gave rise to the nickel-poor hexahedrite type of meteoric iron, and the Bustee and Daniel's Kuil types of meteoric stone, in which calcium is still partly in the form of sulphide and the magnesium silicates contain no iron. Above this zone, it is conceivable, is one of further oxidation, in which part of the iron is also in the state of oxide, but that only in the ferrous condition. This zone would correspond to the other meteoric stones containing ferriferous olivine and bronzite, and a nickel-iron increasingly rich in nickel as it decreased in amount. In this connexion the occurrence in New Zealand and Canada of nickel-iron (awaruite and josephinite) extremely rich in nickel, in association with serpentine and peridotite, is of some significance. In a zone of still higher oxidation, in which all the iron is in the form of oxide, the higher oxides should occur besides the ferrous, and magnetite should be a prominent constituent. Such a zone would correspond to basalt, which recent researches claim as the magma from which all other igneous rocks of the earth's surface have been derived, whether by absorption of sedimentary rocks,[1] or by differentiation controlled by crystallization.[2]

The General Classification of Meteorites, showing their mutual relations.

The Rose-Tschermak-Brezina scheme of classification now generally adopted, in the case of the chondrites is somewhat complicated and divides them into groups which do not appear to have much relation to their chemical and mineral composition.

The following scheme of classification, according to which all the three main classes of meteorites, viz. Chondrites, Achondrites, and Irons, are divided into five groups, each having some characters common to all three classes, serves to express the genetic relationship of meteorites demonstrated in the preceding pages, and also to exhibit their chemical and mineral distinctions. The groups from 1 to 5 may be

[1] R. A. Daly, 'Igneous Rocks and their Origin.' 1914.

[2] N. L. Bowen, 'The later stages of the evolution of the Igneous Rocks.' Journ. Geol., 1915, vol. xxiii, No. 8, Supp.

Class.	Group 1. Iron, poor in Ni. Mg-silicates (Enstatite) almost free from Fe and Ca. Felspar, oligoclase.	Group 2. Iron, less poor in Ni, generally in large amount. Mg-silicates (Bronzite and Olivine) poor in Fe and Ca (MgO : FeO = 4–7). Felspar, oligoclase in chondrites, anorthite in siderolites.	Group 3. Iron, rich in Ni, in less amount. Mg-silicates (Bronzite and Olivine) poor in Ca, but richer in Fe (MgO : FeO = 3–4). Felspar, oligoclase.	Group 4. Iron, richer in Ni, in still less amount. Mg-silicates (Bronzite and Olivine poor in Ca, but still richer in Fe (MgO : FeO = 2–3). Felspar, oligoclase.	Group 5. Iron, little or none. Mg-silicates (Bronzite, Olivine, and Augite) richer in Ca as well as in Fe. Felspar, anorthite.
Chondrites Symbol	Daniel's Kuil (Hvittis) Type. C 1	Cronstad Type. C 2	Baroti Type. C 3	Soko-Banja Type. C 4	— C 5
Achondrites (non-chondritic stones) Symbol	Bustites (including Bishopville). A 1	Siderolites (including Lithosiderites). Ureilites. A 2	— A 3	Chladnites (Diogenites). Chassignites. Amphoterites. Rodites. A 4	Angrite. Nakhlite. Howardite. Eucrite. Sherghottite. A 5
Irons (Siderites) Symbol	Hexahedrites. Nickel-poor Octahedrites. Nickel-poor Ataxites. S 1	Most Octahedrites. Nickel-poor Ataxites. S 2	Nickel-rich Octahedrites. Nickel-rich Ataxites. S 3	Ataxites still richer in Ni. S 4	— S 5

regarded as corresponding to different magmas progressively richer in oxygen, each of which has given rise to members of all three classes of meteorites.

According to this scheme, which may be used as subsidiary to the present classification in all cases where the chemical composition of the meteorite has been determined, the chondritic stones are divided into four groups corresponding to the Daniel's Kuil (Hvittis), Cronstad, Baroti, and Soko-Banja types, and may be distinguished by the symbols C1–C4. Under these same four groups can be arranged the meteoric irons (Siderites), with symbols S1–S4, according to their richness in nickel, and also most of the non-chondritic stones, with symbols A1–A4, according to the richness in iron of their magnesium silicates. A fifth group (A5) is added for the remainder of the non-chondritic stones (angrites, nakhlites, howardites, eucrites, and sherghottites), in which the magnesium silicates are richest in iron, since they are also richer in lime, and (with the exception of El Nakhla) in alumina, than any chondritic stones of which the chemical composition has been determined.

The main principle of classification of the meteoric stones is the ratio of MgO to FeO in the magnesium silicates, and its interrelation with the richness in nickel of the nickel-iron. The further interrelation with the amount of nickel-iron is true for most stones, but is liable to a few exceptions amongst the achondrites (see list on p. 36), and possibly also amongst the chondrites (see list on p. 33).

Conclusions.

The source of all meteorites, and possibly by analogy of all terrestrial rocks, was a nickel-poor nickel-iron containing originally also other unoxidized metals, principally Mg, Al, Ca, Na, and Cr, and non-metals, principally Si, S, and C. In the magma which gave rise to such meteorites as the rare Bustee type of non-chondritic stone and the Daniel's Kuil (Hvittis) type of chondritic stone, sufficient oxygen had been added to the original nickel-iron to form oxides with the Mg, Si, Al, Na, but only partially with Ca and Cr, and scarcely at all with Fe. These meteorites therefore consist mainly of a metasilicate of magnesium, enstatite, free from iron, a nickel-poor nickeliferous iron, a sulphide of iron, troilite, a sulphide of calcium, oldhamite, a sulphide of chromium and iron, daubreelite, and an acid soda-lime felspar. By a further accession of oxygen, part of the iron also became converted into oxide,

and a reaction was then possible which led to the production of iron-bearing olivine and bronzite instead of pure enstatite. Under surface conditions this action may have given rise to the chondrules of chondritic stones. In this process the nickel escaped oxidation so long as any iron remained in the metallic state, and consequently this residual iron became increasingly enriched in nickel. Therefore, *in meteoric stones generally, the poorer they are in nickel-iron, the richer that iron is in nickel, and the richer in iron are the magnesium silicates.*

The classification proposed in order to illustrate this genetic relationship of meteorites divides the chondritic stones into four groups corresponding to the four types (1) Daniel's Kuil (Hvittis), (2) Cronstad, (3) Baroti, (4) Soko-Banja, which contain in order decreasing amounts of nickel-iron increasingly rich in nickel, and magnesium silicates increasingly rich in ferrous oxide. Under the same four groups fall the meteoric irons according to their richness in nickel, and most of the non-chondritic stones according to the richness in ferrous oxide of their magnesium silicates. A fifth group is added for the remaining non-chondritic stones, which are somewhat richer in lime and generally also in alumina than any chondritic stones of which the chemical composition is known.

The isolation of the directions-image of small objects.

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THERE are two distinct kinds of image which are the subject of optical investigation: object-images, in which the form of the object is reproduced, and directions-images, in which every point represents a direction followed by light before reaching the objective. An instrument that shows a directions-image may be described as a hodoscope.[1] It is focused not on the object but on infinity, so that parallel rays are collected at the same point in the image. Such an instrument is the telescope employed in the determination of the critical angle of total reflection, or in goniometric measurements, or a microscope modified for the observation of the interference-figures of crystalline substances. There is, however, this difference, that in the last the angular aperture is made as large as possible, whereas in the telescope it is comparatively small.

Where it is desired to study the directions-image of a comparatively small object, a difficulty arises that a portion of the light illuminating the directions-image does not come from the object under investigation, and must be excluded if the directions-image is to be studied to the best advantage. If the observation is between crossed nicols, only the light traversing other anisotropic substances will interfere with the effects to be studied, but in other cases even diffused light from the medium in which the object lies will interfere with the observation.

[1] This term, from ὁδός, a path, was first suggested by the author in Journ. Quekett Microscopical Club, 1915, vol. xii, p. 613. The instrument has also been called a konoscope, but this is misleading, for it is the individual directions, not the cone that includes them, which are studied.

This exclusion of extraneous light from the directions-image of an object may be described as the *isolation* of its directions-image. Isolation may be carried out by means of some form of diaphragm, which must either be interposed in the path of the light before it reaches the object, so as to prevent the illumination of adjoining objects, or in the path of the light after it has passed the object, so as to cut off all light that has not traversed it or (in the case of the goniometer) reflected from it. For the isolation to be effective the diaphragm must either be in close proximity to the object, or else in a focus conjugate to it, so that the image of the aperture of the diaphragm and the object are seen together.

The application of these principles to the directions-image in a petrological microscope will be first considered.

Attempts have been made in the case of a mineral in a thin section to effect the isolation by painting either the glass slip or the cover-glass with opaque material. This is obviously a difficult and tedious process, which has little to recommend it except its simplicity and directness.

The method most frequently employed at present is only applicable when the directions-image is studied in the principal focus of the objective after the removal of the eyepiece (Lasaulx method). The process of isolation appears to have been originally described by S. Czapski (Zeits. Kryst. Min., 1894, vol. xxii, pp. 160, 161). The microscope is adjusted by the focusing screw till the primary object-image is brought to the upper end of the tube. To ascertain when this has been effected, a lens should be focused on the place where the object-image is to be formed. Then by moving the glass slip carrying the section about the stage, the image of the object is brought into the centre of the field, and a cap with an aperture in the centre, not exceeding the size of this image, is placed on the eyepiece. The lens is now removed and the eye applied to the aperture in the diaphragm, when the directions-image of the object will be seen unaffected by any extraneous light. Czapski employed for this purpose what is known as the Czapski eyepiece, an iris-diaphragm surmounted by a Ramsden eyepiece, focused on the diaphragm. The microscope is focused so as to bring an object-image into the plane of the diaphragm, which is adjusted so as to exclude everything except the object to be examined. The Ramsden eyepiece is then removed and the directions-image examined through the diaphragm.

E. Sommerfeldt (Zeits. wiss. Mikr., 1905, vol. xxii, pp 361–362) and F. E. Wright (Amer. Journ. Sci., 1910, vol. xxix, p. 412) have each devised a system of slides by which the aperture may be accommodated

to the shape and size of the object and the maximum amount of illumination of the directions-image obtained. This is, however, only possible when the stage is fixed. With a rotating stage there is no advantage in having an aperture of any shape other than circular, and the adjustment of the aperture of the diaphragm so as to coincide with the image of the centre of rotation of the object becomes important.

If the image is observed by means of the Bertrand (Amici) lens, the question of isolation is not so simple. There is, as a matter of fact, an object-image formed above the Bertrand lens and below the eyepiece, and if a diaphragm were inserted there, isolation could be effected. It would however, be necessary to remove the eyepiece and insert another lens, or use a lens in combination with the eyepiece, to see the object-image, so as to be able to bring it into the position of the diaphragm by focusing and adjust the aperture of the diaphragm. (S. Czapski, loc. cit., p. 162.) This method is, as a matter of fact, never employed, as it involves the cutting of a new slot in the microscope tube, but a diaphragm is frequently placed immediately above or below the Bertrand lens so that it can be inserted in the same slot. If it be placed above the Bertrand lens, a comparatively small elevation of the microscope will bring the object-image to the position of the diaphragm, but the consequent increase in the distance of the objective from the object will seriously diminish the angular aperture of the instrument as a hodoscope, so far as concerns the directions traversing the object. If, however, as is usually the case, the diaphragm be placed below the Bertrand lens (C. Leiss, 'Die optischen Instrumente, &c.,' Leipzig, 1899, p. 190; and E. E. Wright, 'The Methods of Petrographic-Microscopic Research,' Carnegie Institution, Washington, 1911, p. 59), a far greater elevation of the microscope is required, for the Bertrand lens then no longer assists in bringing the object-image down to the diaphragm. The result is that the angular aperture is so contracted that the directions-image is of very little value, or would be, if isolation were completely effected by the coincidence of the directions-image with the diaphragm. Apparently, however, when such a diaphragm is employed, no precautions are as a rule taken to see that complete isolation is secured, and the directions-image, though greatly contracted, is more or less affected by the presence of extraneous light.

An alternative method, when the Bertrand lens is employed, is to make use of a small image of the object that is then formed above the eyepiece (F. Becke, Min. Petr. Mitt., 1894, vol. xiv, p. 378). If a cap

or other diaphragm be placed in this position and the image of the object observed by means of a lens, the diaphragm may be adjusted so as to exclude the rest of the field. The lens may then be laid aside and the directions-image examined through the aperture in the diaphragm. A preliminary centring of the object may be effected before the insertion of the Bertrand lens in the ordinary object-image seen in the focus of the eyepiece.

All these methods have serious disadvantages. If the eyepiece be removed (Lasaulx method), the directions-image is very small, while in the two methods in which the Bertrand lens is employed, the real object-image, in which isolation is effected, is but slightly magnified; so that in the case of small minerals or narrow twin-lamellæ, the perforation in the diaphragm must be very minute and its adjustment a tedious process.

These difficulties are avoided by adopting the method proposed by Becke (loc. cit., pp. 375–378), which has the further advantage that it does not require any interference with the microscopic tube. Instead of inserting the Bertrand lens in the tube the directions-image is obtained by placing over the ordinary eyepiece a lens, or system of lenses essentially similar to a Ramsden eyepiece, in a suitable fitting. This accessory, which is known as the Klein or Becke lens, magnifies the small directions-image which is formed in the Ramsden circle. It should be capable of an up and down movement by which it may be focused.[1]

The object-image is first observed in the focus of the eyepiece in the usual manner, and the object to be examined is brought into the centre of the field. A diaphragm is then inserted through the slot in the focus of the eyepiece, so that only the object under investigation is visible. The Becke lens is now placed in position, and the directions-image, even of very small minerals, will be seen entirely unmixed with extraneous light.

The observation and magnification of the directions-image in the Ramsden circle were first carried out by C. Klein (Sitzungsber. Preuss. Akad., 1893, p. 222, note 1, and p. 226). He inserted the 'No. 1' or 'No. 2' eyepiece in the tube of the microscope and superposed the 'No. 2' or 'No. 3' eyepiece to get the necessary magnification of the small directions-image. Becke, however, appears to have been the first to provide a special fitting for the purpose, and to employ in conjunction with it a diaphragm in the focus of the eyepiece for the purpose of isola-

[1] The position will vary according to the objective employed, the eye of the observer, and the part of the field under investigation.

tion, and a scale for measurement of the directions-image in the focus of the lens. It was originally employed by him in conjunction with the Czapski eyepiece, on which it was superposed after the diaphragm had been adjusted.

It is curious that although the Becke lens was employed by Becke specially with a view to the isolation of the directions-image of small minerals, this is not referred to in any of the textbooks which mention the lens, and I personally used this method of isolation for some time before I was aware that it had been described.

The advantage of the Becke method of isolation is that the real object-image is considerably magnified, which facilitates the adjustments, especially in the case of minute objects, since the movements required in the adjustment of the diaphragm are correspondingly larger than they would be with a smaller image. The further magnification by the eye-lens of the eyepiece is also of assistance. If the stage is fixed, the shape of the diaphragm can be adjusted to that of the object in any way which may be convenient (see p. 47). If not, the centring of the object and aperture with the image of the centre of rotation is, of course, important.

I recently devised a method of isolation in which the diaphragm is placed below the condenser, which is adjusted so that the perforation in the diaphragm is seen in the microscope simultaneously with the object-image, and is adjusted so that only the mineral under observation is illuminated. If the stage rotates, the object must of course be brought into the centre of rotation, and so must the condenser and the image of the aperture in the diaphragm.

This procedure has the advantage that it may be employed with any method of observing the directions-image. On the other hand, the conjugate image[1] of the object in the position of the diaphragm is comparatively small, unless it is much farther from the condenser than the object, in which case the angular aperture of the illumination would be considerably diminished. The adjustment of the diaphragm therefore requires more care than if the procedure devised by Becke be employed.

The isolation of the directions-image in optical instruments with only a small angular aperture must proceed of course on the same general lines as in the petrological microscope. As a rule, the instrument by which the directions-image is observed in such cases is primarily a tele-

[1] This is not, of course, a real image, though it would become real if the direction of the transmission of the light were reversed.

scope, but it can be converted into a microscope by placing a lens either in front of the objective or behind the eyepiece, that is to say, between it and the observer.

In the former case the isolating diaphragm cannot be on the side of the lens nearer the eye, for the whole ocular system is transformed by the removal of the lens. It may be placed in close proximity to the object so as to restrict the light either before or after reaching it. H. L. Bowman (Mineralogical Magazine, 1908, vol. xv, pp. 177–179) adopted the former course in determining the angular position of the laminae of perovskite by a goniometer and confined the illumination to a single lamina by placing a perforated screen in close proximity to the mineral.

The diaphragm may also be placed at a focus of the collimator lens conjugate to the object. This will be on the same side of the lens as the signal but at a greater distance. The perforation in the diaphragm can then be adjusted so that the illumination is confined to the crystal, or portion of the crystal, under examination. This method is quite satisfactory, and is probably the best where the observing telescope is converted into a microscope by a lens placed before the objective.

The most convenient arrangements, however, are those in which the observing instrument is transformed from a telescope to a microscope, or vice versa, by the interposition of a lens or system of lenses behind the eyepiece.

It appears to have been S. Czapski (Zeits. Instrumentenk., 1893, vol. xiii, p. 5) in his two-circle goniometer who first converted the observing telescope into a microscope by placing a lens behind the eyepiece so as to magnify the object-image that is formed just outside it, and by placing a perforated diaphragm in this position excluded all light except that coming from the object under investigation. When the diaphragm was adjusted the extra lens was thrown out and the isolated directions-image seen through the aperture in the diaphragm.[1] He was followed in this procedure by C. Pulfrich (Zeits. Instrumentenk., 1899, vol. xix, pp. 5, 6) and C. Leiss (ibid., 1902, vol. xxii, p. 332), who applied it in instruments for determining the critical angle of total reflection. The chief objection to this method is the small size of the image where the diaphragm is applied, which makes the manipulation of the latter difficult with minute objects.

For this reason a preferable course would seem to be to reverse the process and, as in the examination of interference-figures, to employ an

[1] See also V. Souza-Brandão, Zeits Kryst. Min., 1908, vol. xlv, pp. 331, 332.

instrument which is primarily a microscope, and convert it into a telescope by the addition of a lens.

A. Hutchinson (Mineralogical Magazine, 1911, vol. xvi, pp. 102–105) has done this in his 'Universal Goniometer', which is mainly employed in carrying out the Kohlrausch method of determining the critical angle of total reflection. He employs a microscope of considerable magnification and converts it into a telescope, focused on infinity, by inserting the Bertrand lens. No provision is, however, made for isolation. This could, of course, be effected by employing in place of the Bertrand lens the Becke lens in the manner already described. For this purpose it should admit of sufficient movement to enable the directions-image to be focused even when a low power objective is in use.

A method of determining the angular direction represented by a point in the directions-image of an object under the microscope.

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[Read January 18, 1916.]

THE determination of the direction in which the light illuminating a point in a directions-image (the so-called image in convergent light) was travelling when it reached the objective has hitherto been carried out by first measuring the position of the point in the image and thence calculating the angular direction it represents. It is usually assumed that the distance of a point in the image from the centre of the field is in proportion to the sine of the angle between the path of the light that illuminates the point and the axis of the microscope. The position of the point is accordingly generally fixed in polar co-ordinates by measuring the central distance by means of a micrometer screw or scale, and determining the azimuth, relatively to a definite direction on the stage or object, by means of a radial engraved line or pointer, which can be rotated round the centre of the field or remains fixed while the stage is rotated. Sometimes a net of radiating lines and concentric circles is employed and gives at once not only the central distance, but also, provided the stage be in a definite position, the azimuth as well. F. Becke[1] obtained a similar result with a rotating stage by drawing the interference-figures, by means of a camera lucida, on a rotating disc connected by a cord with the stage, so that both moved simultaneously through the same angles.

Others have employed rectilinear co-ordinates, making the necessary

[1] F. Becke, Min. Petr. Mitt., 1895, vol. xiv, pp. 563–565.

measurements either by means of two micrometer screws at right angles to each other, or a net with square meshes.[1]

Whatever be the accessory employed for measurement, it must be inserted in a position occupied by a directions-image, or a conjugate focus of such an image, so that it may be visible in focus to the observer simultaneously with this image. It is usually placed in the focus of the eyepiece, when a Bertrand (Amici) lens is employed to give the directions-image; or in the focus of the Becke (Klein) lens, when that is substituted.[2] It may, on the other hand, be placed in the principal focus of the objective, or even in its internal focus,[3] or in a conjugate focus below the condenser. E. Sommerfeldt[4] had a scale engraved on the plane surface of the lowest lens of the condenser. F. E. Wright[5] had a graduated glass hemisphere constructed, the spherical surface of which was engraved with circles having their centres on the normal to the plane surface, and with lines radiating from it. This he employed for a number of different purposes, including that of an apertometer. If, however, the radius were sufficiently large, say forty or fifty millimetres, and the plane surface at right angles to the microscope axis, the graduations would be visible simultaneously with the directions-image of a crystal plate resting on it with a film of highly refracting liquid between. There would, however, be some difficulty in illuminating all the directions in a hemisphere of such size.

Whatever the position in which the means of measurement is placed, it requires careful calibration with the help of some form of apertometer such as that invented by Abbé, or by the observation of mineral plates, certain directions in which make known angles with the normal and can be easily recognized in the directions-image. In the latter case the refraction at the surface of the plate must of course be allowed for.

As the sine law is only approximate, the calibration must be carried out for more than one central distance and even for different azimuths, and this is obviously none the less the case when the scale or net purports to give directly the angular distance of the path of the light from

[1] F. E. Wright, Amer. Journ. Sci., 1907, vol. xxiv, pp. 336–337; ibid., 1910, vol. xxix, p. 423; Journ. Wash. Acad. Sci., 1911, vol. i, pp. 60–61; Min. Petr. Mitt., 1908, vol. xxvii, pp. 298–300.

[2] F. Becke, Min. Petr. Mitt., 1894, vol. xiv, pp. 376–378.

[3] H. Lenk, Zeits. Kryst. Min., 1896, vol. xxv, pp. 379–380.

[4] E. Sommerfeldt, Zeits. wiss. Mikr., 1905, vol. xxii, pp. 356–362.

[5] F. E. Wright, 'The Methods of Petrographic-Microscopic Research.' Carnegie Institution, Washington, 1911, pp. 174–175.

the axis, instead of the central distance of the corresponding point in the image.

I propose, on the other hand, to obtain the angular position of a point in the directions-image by the following procedure, which obviates the necessity for calibration and avoids all difficulties due to imperfections in the construction of the lens, the adjustment of the microscope, or the rotation of the stage.

A circular disc is prepared comparable in size with the microscope stage. On this a network of concentric and radial lines is delineated, the radial lines at intervals of 5°, except near the centre, where they are at intervals of 10°, and the concentric lines at distances from the centre equal to $r \tan \theta$, where r is a convenient length, say 50 mm., and θ represents successive angles differing by 5°. The net is therefore a gnomonic projection of the points where a sphere is intersected by lines at equal intervals of azimuth and of angular distance from the normal to the plate through its centre. The circles are numbered with the corresponding value of θ, and the angles of azimuth are numbered counter-clockwise, like the degrees on the rotating stage or the circle on which the movements of rotating nicols are recorded.

The plate is notched at the circumference, or perforated, at three points so that it can be rapidly fitted on corresponding supports on the stage in one definite position relatively to it, and as quickly removed. In this position it is raised a little above the stage so that it does not interfere with a glass slip and rock-section resting on the stage, or the clip, or clips holding it.[1]

When it is desired to determine the angular position represented by a point in a directions-image of a crystal section (usually a thin section of a mineral in a rock-slice), the end of a movable pointer, inserted in any position where it is in focus simultaneously with the directions-image, is made to coincide with it. When the position of the point in the directions-image has been thus recorded, the microscope is raised by the coarse adjustment, and, after the plate has been placed on its supports, adjusted so that the lower surface of the objective is at a distance exactly equal to r from the plate. This may be effected by placing a rod

[1] A plate with a similar arrangement of concentric lines appears to have been employed as an apertometer by W. Volkmann (Aus Theorie und Praxis des Mikroskopes, Berichte über Appar. u. Anlag. von Leppin & Masche, Berlin, 1911, vol. viii, p. 5, noticed by E. A. Wülfing, Fortschritte Min. Krist. Petr., 1913, vol. iii, pp. 71, 78), but I have not been able to see the original description.

of that length on the plate, at right angles to it, and focusing the microscope down till the lowest surface of the objective touches the end, or a mark indicating this point may be engraved on the rackwork. The distance to which the microscope can be racked back places an obvious limit to the magnitude of r, but it is usually possible to make it equal to 50 mm. If an objective with a working distance of not more than 6 mm. be at a distance of at least 50 mm. from the plate, the net is clearly visible in the microscope when the Bertrand or Becke lens is inserted, or the microscope is otherwise converted into a hodoscope (p. 45 above).

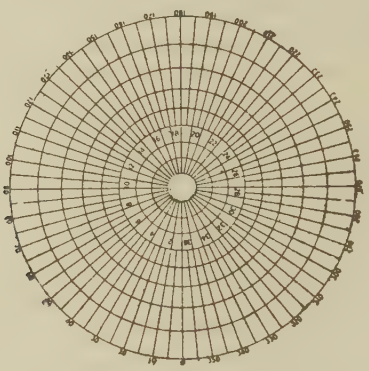
The relation of any point in the field to the image of the net will then indicate the angular position of the path of the light that illuminates it, and likewise that of the light which previously illuminated the same point in the directions-image of the crystal section. The position of the end of the pointer relatively to the image of the net will therefore give at once the angular position required.

The most important advantage of this method is that every peculiarity in the construction or adjustment of the microscope will affect the light coming from the plate as it does that illuminating the directions-image, so that no calibration or correction will be required. In microscopes with a rotating stage the plate and object both rotate with the stage so that all measurements of azimuth with the net will have reference to the same zero direction in the object and plate, whatever may be the position of the stage. The plate should be so adjusted that the zero direction in it coincides with the right and left cross-wire, and is on the right when the index reading of the stage is at zero.

It is of course desirable that the plate should be as nearly as possible at right angles to the axis of the microscope and the axis of rotation, and that the centre of the plate should lie in these axes, which should of course coincide with one another. It is hardly necessary to explain that the angular position determined in this way is that at which the light meets the outer surface of the objective. To obtain the angular position in a crystal section or other object, correction must be made for refraction at its surface. In the case of a crystal section, if θ be the angular distance of the path in the crystal plate from the normal, and ϕ that of the path in air, and μ is the refractive index of the crystal section for the vibrations of the light under examination, $\mu \sin \theta = \sin \phi$.

The procedure may be varied, if desired, by placing the end of another pointer on the plate in such a position that its image coincides with that of the end of the pointer employed to record the position of a particular

point in the directions-image. The corresponding angular position can then be read off directly from the plate by observing the position relatively to the net of the end of the pointer resting on the plate.



In the plate shown in the accompanying text-figure, which was made by Messrs. J. Swift & Son, a circular hole was, at my suggestion, left in the centre, so that the crystal section could be observed through it. I do not think, however, that there is much advantage in this, since, with a little practice, the plate can be rapidly placed in position and removed. I also stipulated that the plate should not be so large as to cover up the graduations on the stage, but there seems no reason why it should not do so, and have as great a diameter as the construction of the microscope permits, so that the angular distance from the axis that can be determined should be as large as possible instead of being restricted to 45°.

Similar results may be obtained by substituting for the plate a larger net, with r equal to say 200 mm., on a wall or vertical screen. When the pointer has been placed in position on the directions-image in the manner already explained, the glass slip with the crystal section and the substage are removed and the microscope racked down through the aperture in the stage, and then brought to a horizontal position opposite the centre of the net and at right angles to it with the objective at a distance r from it.

The angular position represented by the end of the pointer may then be determined, either by observing its relation to the image of the net or by an assistant moving, under the directions of the observer, the end of a pointer resting on the actual net until it is seen to be in apparent coin-

cidence with the end of the pointer in the microscope. In the latter case, the angular position required may be read off from the net itself.

If this method be employed, it would be of advantage to use a microscope with a mechanical stage so that the object could, after removal to allow of the racking down of the microscope, be brought back to exactly the same position and orientation, if it were desired to make further observations. It is obviously unsuited to a microscope in which the stage and not the nicols rotates, as the net cannot well be made to rotate with the stage.

The use of a scale on a wall for calibration of the directions-image of a microscope has long been practised at Heidelberg (E. A. Wülfing, Fortschritte Min. Krist. Petr., 1913, vol. iii, p. 78).

On a series of volcanic rocks from the neighbourhood of the Lucalla River, Angola.

(*With Plate V.*)

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With Analyses by H. F. Harwood, M.Sc., Ph.D.

[Read June 20, 1916.]

I. Introduction.
II. Porphyritic Basalts.
III. Nephelinite.
IV. Trachytes.
V. Augite-andesite.
(Near the Lucalla River, 30 miles north of Cambambe.)
VI. General Discussion.
VII. Note on a Basanite from Dombe Grande, near Benguella.

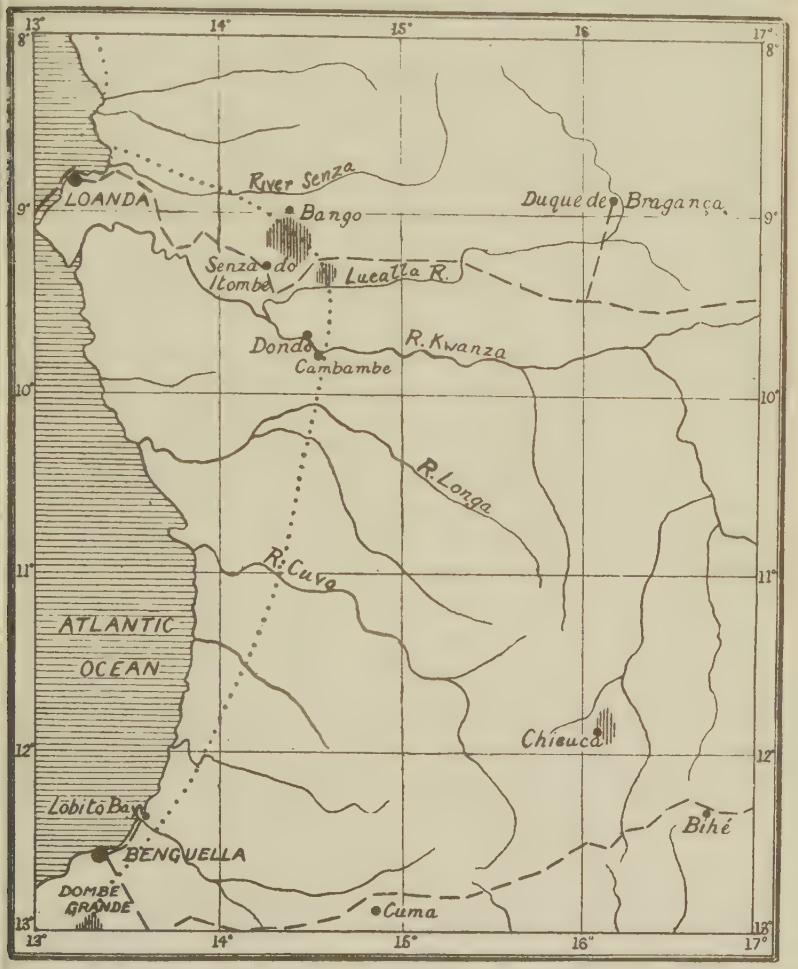
I. Introduction.

LAST year, while working through the geographical collection of rocks in the Geological Department of the Imperial College, I found an interesting series of volcanic rocks from the neighbourhood of the Lucalla River in the district of Cambambe, Angola, which hitherto has not been described. The specimens were collected about the year 1860 by J. J. Monteiro,[1] a former student of the Royal School of Mines, who

[1] J. J. Monteiro, 'Angola and the River Congo,' 1875, vol. ii, p. 69, writes: 'A very interesting excursion was one I made [from Cambambe] about thirty miles in a northern direction, where I passed through most beautiful mountain scenery, the formation of the country being trachyte.' On pp. 65 and 70, he mentions the series of lavas lying between Senza do Itombe and Bango, and suggests that the two occurrences are connected.

See also P. Choffat, 'Coup d'œil sur la géologie de la province d'Angola.' Comm. Dir. Trab. Geol. Portugal, 1895–6, vol. iii, pp. 84–91.

devoted many years to the exploration of Angola. The collection, though consisting of only ten specimens, comprises porphyritic basalts, alkali-trachytes, a nephelinite allied to monchiquite, and an augite-andesite. With the permission of Professor W. W. Watts the rocks were investi-



— — — — Railways. Alkaline Igneous Rocks.
. . . . . Approximate Boundary between the Coastal Belt (Tertiary and Cretaceous formations with local basins of Upper Karroo rocks) and the Archaean Platform.

Sketch-Map of part of Angola.

gated by Dr. H. F. Harwood and myself, the results being embodied in the present paper.

A series of igneous rocks of Tertiary age from a neighbouring locality—between Senza do Itombe and Bango—has already been described, briefly by Senhor Pereira da Sousa,[1] and in greater detail by myself.[2] The specimens were collected by my friend Colonel Freire d'Andrade in 1906, and include phonolites accompanied by nepheline-syenite and nepheline-monchiquite.[3]

Unfortunately the age of the rocks collected by Monteiro cannot yet be stated more definitely than that it is post-Karroo. It is significant, however, that they occur, like their neighbours to the north-west (which are known to be of post-Cretaceous age), along the boundary between the sedimentary rocks of the coastal plain and the crystalline rocks of the Archaean belt that lies to the east. On the locality map (see p. 59) the approximate position of this boundary has been sketched in. It will be noticed that volcanic rocks again make an appearance at Dombe Grande, south of Benguella. A collection of rocks from this locality, made by L. Malheiro between the years 1882–6, included two fragments that were determined by J. P. Gomes as 'liparite' and 'nepheline-basalt' respectively.[4] Prof. P. Choffat has kindly sent to me the original sections on which the identifications were based. The 'liparite' is an arenaceous limestone, and the 'nepheline-basalt' is described below as a basanite (p. 73). The lavas of Dombe Grande lie partly on a foraminiferal oolitic limestone of Miocene age and partly on mica-schist belonging to the Archaean belt.

Basaltic rocks are very common between Benguella and Mossamedes, and are responsible for numerous small mesas rising to a height of 200–300 feet never far from the coast. Monteiro describes the lavas as amygdaloids containing heulandite and calcite in great abundance.[5] These again are of Tertiary age and lie over the boundary between the crystalline and sedimentary formations.

[1] Pereira da Sousa, C. R. Acad. Sci. Paris, 1913, vol. clvii, p. 1450.

[2] A. Holmes, Geol. Mag., 1915. dec. 6, vol. ii, pp. 228–232, 322–328, and 366–370. See also G. Berg, Min. Petr. Mitt., 1903, vol. xxii, p. 359.

[3] These are probably the 'trap rocks' encountered by Livingstone almost at the commencement of his journey from Loanda to the Zambesi. 'Travels in South Africa,' 1857, p. 398.

[4] P. Choffat, loc. cit., pp. 89 and 90. J. P. Gomes, Comm. Dir. Trab. Geol. Portugal, 1896-8, vol. iii, p. 239.

[5] J. J. Monteiro, loc. cit., p. 220.

II. Porphyritic Basalts. (Plate V, fig. 1.)

The basalts are dark grey rocks having large porphyritic crystals of labradorite up to 3 cm. in length. The specific gravity of the specimens lie between 2·70 and 2·71, while that of the porphyritic felspar is 2·685. In one case (545) the rock is pitted with nearly spherical vesicles averaging 3 mm. in diameter and carrying a powdery lining of opal. In No. 548 analcime is present, though in small amount. Treated with acid the rocks effervesce slightly, giving off sulphuretted hydrogen, a fact which points to the presence of pyrrhotite. Here and there small tarnished specks of the mineral can be seen in the hand-specimens.

Under the microscope the following minerals are recognized:

Phenocrysts:

Labradorite, macro-porphyritic and micro-porphyritic: average refractive index, 1·56.

Olivine, micro-phenocrysts.

Purple-brown augite (rare), micro-porphyritic.

Groundmass:

Labradorite: average refractive index 1·56.

Alkali felspar: average refractive index 1·525.

Purple-brown augite accompanied by aegirine-augite.

Titaniferous magnetite and pyrrhotite.

Analcime and apatite in specimen No. 548.

Vesicles:

Opal in No. 545: $n=1{\cdot}45$.

Analcime in No. 548: n between 1·481 and 1·49.

The groundmass makes up rather less than half the rock. In it the three groups of minerals, felspars, pyroxenes, and iron-ores, are present in roughly equal proportions. The structure approaches the intersertal type, laths of labradorite separating grains of pyroxene. Most of the latter display purple tints and are presumably titaniferous, but a few have the colour and pleochroism of aegirine-augite. Between the felspar laths and the pyroxene and iron-ore granules, there are limpid spaces occupied sometimes by untwinned orthoclase which includes minute needles of what is probably apatite, and sometimes (in 548) by an isotropic constituent, the refractive index of which agrees with that of analcime.

Set in this groundmass are large prismatic phenocrysts of labradorite, accompanied by smaller ones that are only visible in thin section.

Extinction-angles (e.g. 18° on brachy-pinakoidal cleavage fragments), refractive index, and specific gravity indicate that the composition is between Ab_5An_5 and Ab_4An_6. Inclusions of iron-ores are common, particularly towards the margins. A few highly refractive blebs are also present, and their high double refraction suggests their identity with either zircon or rutile. Around the borders of the felspars the melanocratic minerals are sometimes noticeably concentrated. Olivine occurs only in one generation, and is remarkably fresh, serpentine being found only along a few microscopic cracks. Micro-porphyritic crystals of augite—pleochroic from purple-brown to straw-yellow—are sometimes moulded around a nucleus of olivine, but otherwise phenocrysts of augite are rare.

An analysis of specimen 548 was made by Dr. Harwood with the following results:

	Percentages.	Molecular Proportions.
SiO_2 ...	47·98	... 800
Al_2O_3 ...	21·68	... 213
Fe_2O_3 ...	0·58	... 4
FeO ...	8·28	... 115
MgO ...	3·13	... 78
CaO ...	8·63	... 154
Na_2O ...	3·65	... 59
K_2O ...	2·06	... 22
H_2O ...	0·73	... —
H_2O (at 105° C.)	0·72	... —
TiO_2 ...	2·24	... 28
ZrO_2 ...	0·02	... —
P_2O_5 ...	0·06	... —
MnO ...	0·16	... 2
BaO ...	0·16	... 1
SrO ...	trace	... —
S ...	0·09	... 3
	100·17	
less O for S	0·04	
	100·13	

Specific gravity 2·71

Mineral Composition ('Norm').			
Orthoclase ...	12·23	} 75·91	
Albite ...	22·32		
Anorthite ...	36·70		
Nepheline ...	4·66		
Diopside ...	5·35	} 22·61	
Olivine ...	11·89		
Magnetite ...	0·93		
Ilmenite ...	4·26		
Pyrite ...	0·18		
Water ...	1·45		
	99·97		

Class II ...	Dosalane
Order 5 ...	Germanare
Rang 3 ...	Andase (nearly Hessase)
Subrang 4 ...	Andose (nearly Hessose)

The rock bears a close resemblance to the Markle type of the Scottish Carboniferous basalts, not only in chemical composition, but also in structure and mineral composition.[1] This being the case it is interesting to note that farther south in Angola there is a porphyritic olivine-basalt (Kiticingue, Portichicorcoo) that resembles the Dunsapie type.[2] Speci-

[1] F. H. Hatch, Trans. Roy. Soc. Edinburgh, 1892, vol. xxxvii, p. 119. G. W. Tyrrell, Trans. Geol. Soc. Glasgow, 1912, vol. xiv, p. 241.

[2] Ibid., p. 245.

mens were collected by Mr. R. J. Cuninghame and are now in the British Museum (Natural History), where I was kindly allowed to see them by Dr. G. T. Prior. The rock has a groundmass of labradorite laths with grains of purple augite, much iron-ore, and a little olivine. Phenocrysts are present, generally in glomero-porphyritic masses, consisting of labradorite (with inclusions of augite, iron-ore, and blebs of groundmass); augite zoned in tints of purple and straw-yellow and exhibiting beautifully developed hour-glass structure; and olivine seamed with veins of serpentine.[1]

III. Nephelinite. (Plate V, fig. 3.)

This is a dark grey, compact rock (546) speckled with small phenocrysts of pyroxene, and with straw-yellow to red coloured patches that seem to be characterized by the presence of nepheline. Specific gravity 2·85.

The minerals present as seen under the microscope are:

Phenocrysts.	Groundmass.
Nepheline.	Nepheline.
Analcime.	Analcime.
Aegirine.	Orthoclase.
Aegirine-augite.	Calcite.
Purple augite.	
Grey-green augite.	
Barkevikite.	
Sphene.	
Apatite.	
Titaniferous magnetite.	

Pyroxenes, forming a continuous series including the varieties named above, are by far the most abundant minerals present. In many of the largest crystals (1 × 2 mm.), which are idiomorphic, the colours are patchy, and irregular zoning may be seen. Generally the interior is mainly aegirine or aegirine-augite, while the borders, and particularly the terminations (along the *c*-axis), are of a purple colour. On the contrary, the small crystals are largely or even wholly composed of purple augite; aegirine-augite when present is confined to the periphery. Finally, sprinkled among the idiomorphic crystals are irregular grains and blebs

[1] Other basalts and dolerites from the Benguella Plateau have been described by J. P. de Nasciamento, 'A Colonisação de Angola,' Lisbon, 1912, and G. W. Tyrrell, Trans. Roy. Soc. Edinburgh, 1916, vol. li, p. 558.

of grey-green augite. In the larger pyroxenes, apatite and magnetite, probably titaniferous, are present as inclusions.

Ragged shreds of barkevikite—pleochroic from reddish-brown to straw-yellow—may be seen occasionally, the amphibole having grown from the exterior of the pyroxenes, and rarely independently. The extinction angle $Z \wedge c$ is about 10° and the birefringence is moderately high.

Apatite is unusually abundant. It occurs in rounded crystals slightly elongated parallel to the *c*-axis, which are generally crowded with gas pores drawn out parallel to the direction of elongation. For this reason the mineral has a grey or blue appearance in thin section. Similar apatite in a nephelinite from the Little Island of Trinidad has been described by Dr. G. T. Prior.[1] Sphene is present in wedge-shaped crystals of a grey-brown colour. Many of the crystals are twinned and show good pleochroism from greyish-white (X) to light brown (Z). The mineral is often found clinging to the purple terminations of augite crystals or to titaniferous magnetite.

Rounded phenocrysts of nepheline, and isotropic idiomorphic crystals of analcime, sometimes exhibiting a cubic cleavage, are seen in all sections, though they are not uniformly distributed. The same minerals, verified by refractive index measurements and staining methods, are found in the clear transparent groundmass. In addition, however, a certain amount of orthoclase is present. Calcite occurs in small grains as inclusions in analcime and nepheline.

The structure of the rock is far from uniform. Within the main mass of the rock, which is moderately even in texture, and to which the name *nephelinite* is appropriate, there occur irregular patches of two types. The one is finer in grain and darker in colour than the enclosing rock; the other, coarser in grain and lighter in colour. These patches have fairly sharp borders, and are clearly cognate xenoliths or 'enclaves homœogènes' of respectively melanocratic and leucocratic composition relative to that of the surrounding nephelinite. The melanocratic type (fig. 4) consists mainly of pyroxenes with a great abundance of iron-ore; apatite occurs as inclusions, and shreds of biotite and interstitial nepheline are present in small amount. A rock of similar composition would probably be called *jacupirangite*. The leucocratic type is richer in nepheline, altered analcime, and apatite. Aegirine-augite is the chief pyroxene, and sphene and perovskite are present in addition to the

[1] G. T. Prior, Mineralogical Magazine, 1900, vol. xii, p. 322.

iron-ores, which in this case are less prominent. The mineral composition is clearly that of an *ijolite*.

Similar complementary inclusions have been recorded by Lacroix as occurring in the nephelinites of the Oberwiesenthal,[1] and by Stelzner in the nephelinite of Podhorn near Marienbad.[2] Similar leucocratic patches, but including orthoclase, have been found in phonolites from the Little Island of Trinidad[3] and from Fernando Noronha.[4] Although in the present case there is little evidence on which to base an adequate explanation of the origin of the inclusions, the mineral associations of the latter suggest that they are complementary products of differentiation of the magma from which the enclosing nephelinite was crystallized.

IV. Trachytes.

Two varieties of trachyte are represented in Monteiro's collection. Both are characterized by phenocrysts of sanidine, with anorthoclase in the groundmass, but in the one biotite is the chief coloured mineral now recognizable, whereas in the other soda-pyroxenes and amphiboles are abundant, and biotite is absent.

Biotite-Trachyte (560).—The hand specimen is of a cream-grey colour and has a well-marked flow-structure broken here and there by conspicuous prismatic phenocrysts of sanidine, and spangled with shining flakes of biotite.

Under the microscope the only additional minerals that can be determined are anorthoclase, which is present in the groundmass in minute laths, and in radiating groups of needle-like crystals; aegirine, which is developed in minute elongated crystals between the divergent members of groups of anorthoclase needles; and a few grains of magnetite.

The flow-structure is seen in thin section to be controlled by the development of alternate light and dark bands. The former owe their superior transparency to the greater abundance of microliths of anorthoclase. The dark bands are almost opaque on account of the presence of enormous numbers of black globulites, and among these only a few extremely small hair-like felspars can be seen. In each of the bands there are ragged shreds of an obscure reddish-brown alteration product,

[1] A. Lacroix, 'Les Enclaves des roches volcaniques,' 1893, p. 531. For various explanations, see p. 641, et seq.

[2] A. W. Stelzner, Jahrb. k.-k. Geol. Reichsanst. Wien, 1885, vol. xxv, p. 277.

[3] G. T. Prior, Mineralogical Magazine, 1900, vol. xii, pp. 320–321.

[4] O. A. Derby, Amer. Journ. Sci., 1889, vol. xxxvii, p. 185.

and here and there a pleochroic core—reddish-brown to yellowish-green—remains, suggesting a soda-amphibole as the parent material. Similar alteration products represent former amphiboles in the trachytes of Mozambique[1] and the Rift Valley.[2]

The phenocrysts of sanidine are generally corroded by the groundmass, or sharply fractured by flowage. Inclusions of biotite, and grains of iron-ore are present, and many of the crystals are cut through by tongues of groundmass of the dark globulitic type.

Aegirine-Trachyte: (559) (Plate V, fig. 5).—In the hand-specimen of this rock, which is of a pale grey colour, thin prismatic phenocrysts of sanidine twinned on the Carlsbad law, are seen. They vary in length between 5 and 10 mm., and are distributed uniformly through the rock with their long axes parallel.

Under the microscope the following minerals are seen:

Phenocrysts.	Trachytic Groundmass.
Sanidine.	Anorthoclase.
Aegirine and Aegirine-augite.	Aegirine and Aegirine-augite.
Brown alteration products, probably secondary after an amphibole.	Soda-amphiboles.
	Iron-ores.

The phenocrysts of sanidine are idiomorphic and are free from corrosion. Inclusions of soda-pyroxenes and amphiboles, and of magnetite are present, the latter often in strings of small, well-shaped crystals near the periphery. In the groundmass, which has a typical trachytic texture, anorthoclase is by far the most abundant mineral. The laths are beautifully striated by fine lamellar twinning and give a mottled extinction. The extinction-angle is practically straight and the refractive index and double refraction are just perceptibly higher than in sanidine.

Soda-amphiboles are not abundant and, as in the biotite-trachyte, they are largely represented by patches of decomposition products. Around the latter, grains and shreds of aegirine are moulded, and occasionally between the aegirine and the secondary material, cossyrite is present in dark reddish-brown crystals. Elsewhere cossyrite occurs between successive laths of anorthoclase. Sometimes it grows on a nucleus of a katophorite-like amphibole (pleochroic in tints of rose-red, purple-brown,

[1] A. Holmes, Abstr. Proc. Geol. Soc., 1916, No. 994, p. 72.
[2] G. T. Prior, Mineralogical Magazine, 1903, vol. xiii, p. 241.

green, and yellow-green), but in other cases shreds of the latter have grown on cossyrite. It is noteworthy however, that aegirine, wherever the relations can be ascertained, is of later crystallization than either of the amphiboles.

Aegirine, varying to aegirine-augite, is rare as phenocrysts, though occasional idiomorphic crystals diverge the stream of anorthoclase laths. In the groundmass, however, it is abundant in grass-green needles and granular aggregates lying between the felspars. Both amphiboles and pyroxenes appear to have commenced their crystallization before the anorthoclase, and even before sanidine, but to have continued to crystallize beyond the periods of felspar generation.

The rock bears a close resemblance to some of the trachytes of East Africa, the main difference being that most of the latter carry phenocrysts of anorthoclase in addition to those of sanidine. This difference is reflected in the analyses by an excess of soda over potash. In the trachyte from Angola, on the contrary, potash is slightly more abundant than soda. With this exception the aegirine-trachytes of Somaliland, the Höhnel Islands, Lake Baringo, Masailand, and Mt. Meru are closely similar to that here under discussion, especially in the presence of cossyrite and katophorite in addition to the more abundant aegirine. Other similar trachytes are those of São Thomé, St. Helena, the Canary Islands, and the Azores; of Mt. Rotaro, Ischia; of Algersdorf, Bohemia; of the Ravin des Fleurs jaunes, Réunion; and of Mt. Flinders, Queensland.

An analysis of the Angola aegirine-trachyte (specimen No. 559) was made by Dr. Harwood, with the following results:

	Percentages.	Molecular Proportions.
SiO_2 ...	61·02	... 1017
Al_2O_3 ...	18·88	... 185
Fe_2O_3 ...	1·98	... 13
FeO ...	1·86	... 26
MgO ...	0·42	... 10
CaO ...	1·34	... 24
Na_2O ...	5·76	... 93
K_2O ...	6·22	... 66
H_2O ...	1·31	... —
H_2O (at 105° C.)	0·83	... —
TiO_2 ...	0·78	... 10
P_2O_5 ...	0·007	... —
MnO ...	0·23	... 3
SrO ...	trace	... —
	100·63	

Specific gravity 2·46

Mineral Composition ('Norm').

Orthoclase ...	36·70	99·20
Albite ...	48·73	
Anorthite ...	6·67	
Corundum ...	0·20	
Hypersthene ...	1·66	6·36
Olivine ...	0·16	
Magnetite ...	3·02	
Ilmenite ...	1·52	
Water ...	2·14	
	100·70	

Class I ...	Persalane
Order 5 ...	Canadare
Rang 2 ...	Pulaskase
Subrang 3 ...	Pulaskose

This analysis is repeated in the following table for comparison with analyses of some of the trachytes mentioned above. All are conspicuously alkaline types, and except in the Réunion example, potash (by percentage) is in excess of soda. Characteristic features of the analyses are the low magnesia and lime. Titanium and manganese oxides are higher in the Angola trachyte than in average trachyte, most probably on account of the presence of cossyrite.

	A.	B.	C.	D.	E.
SiO_2	61·02	61·49	61·62	64·69	60·58
Al_2O_3	18·88	18·25	18·11	18·34	18·06
Fe_2O_3	1·98	1·77	2·36	—	3·05
FeO	1·86	3·13	1·28	3·44	1·38
MgO	0·42	0·41	0·56	0·50	0·23
CaO	1·34	1·65	1·44	1·72	1·74
Na_2O	5·76	6·78	5·77	4·61	5·01
K_2O	6·22	5·47	7·60	6·46	6·87
H_2O	2·14	0·26	0·78	0·24	1·89
TiO_2	0·78	0·51	0·87	0·31	0·83
MnO	0·23	—	trace	trace	0·04
P_2O_5	0·007	0·09	0·13	0·18	—
BaO	—	—	—	0·09	—
Incl.	—	—	0·15	—	0·07
	100·63	99·81	100·67	100·58	99·75

A. Aegirine-trachyte, near the Lucalla River, 30 miles north of Cambambe, Angola. (Analyst, Harwood.)

B. Phonolitic trachyte, Ravin des Fleurs jaunes, Réunion. (Analyst, Boteau.)

C. Trachyte, Monte Rotaro, Ischia, Italy. (Analyst, Washington.)

D. Trachyte, Algersdorf, Bohemia. (Analyst, Ullik.)

E. Aegirine-soda-trachyte, Mt. Flinders, Queensland. (Analyst, Jensen.)

V. Pyroxene-Andesite. (Plate V, fig. 2.)

This rock (No. 544) is dark grey in colour, and has a well-marked porphyritic texture, the compact groundmass being sprinkled with prismatic phenocrysts of iron-stained andesine averaging 10×5 mm. in size.

In thin section the rock is seen to consist of phenocrysts of andesine, hypersthene, and augite, embedded in a coarsely trachytic groundmass, composed of andesine laths, intersertal grains of yellow-green augite, and a dark interstitial glass crowded with black globulites. Iron-ores—mainly titaniferous magnetite and alteration products—occur as inclusions in the phenocrysts and an occasional apatite is enclosed by hypersthene. In places the groundmass is micro-vesicular, the spaces being occupied by iron-stained opal and chalcedony. Apart from the alteration of some of the iron-ores, the rock is remarkably fresh.

The phenocrysts of andesine are generally idiomorphic, clear, and

glassy, and exhibit characteristic twinning and zoning. The mean refractive index (nearly the same as that of aniseed oil, 1·556) and the extinction-angles, indicate that the composition is about $Ab_{55}\ An_{45}$. Iron-ores, grains of pyroxene, and patches of groundmass, are present as inclusions, and in a few cases the interior is an emulsion of blebs of dark brown glass and granules of yellow-green augite in a skeleton of andesine, surrounded by a clear mantle of andesine of the same composition. The felspar laths of the groundmass are somewhat richer in the albite molecule, for the mean refractive index is nearly that of nitro-benzol, 1·553, corresponding to a composition of $Ab_{60}\ An_{40}$. The only inclusions present are dark globulites.

The pyroxene phenocrysts occur in slightly rounded idiomorphs. Hypersthene was the first to crystallize, and the smaller individuals frequently serve as nuclei to the later crystals of augite. The latter is of a light greenish-brown colour, notably darker than the yellowish grains of the groundmass.

The order of crystallization is easily determined to be as follows:—Apatite and titaniferous magnetite, hypersthene, greenish-brown augite, andesine ($Ab_{55}\ An_{45}$), andesine ($Ab_{60}\ An_{40}$), yellow-green augite, leaving finally black globulites surrounding a residuum of glass. No biotite or orthoclase, corresponding to the potash, shown to be present by analysis, has been seen in any of the sections.

An analysis of the andesite (No. 544) was made by Dr. Harwood, with the following results:—

	Percentages.	Molecular Proportions.
SiO_2	56·14	936
Al_2O_3	17·81	175
Fe_2O_3	2·69	17
FeO	4·67	65
MgO	4·15	104
CaO	6·81	121
Na_2O	3·59	58
K_2O	1·63	17
H_2O	0 67	—
H_2O (at 105° C.)	0·49	—
TiO_2	1·23	15
P_2O_5	0·12	—
MnO	0·08	1
SrO	0·01	—
BaO	0·04	—
	100·13	

Specific gravity 2·68

Mineral Composition ('Norm').

Quartz	7·60	75·24
Orthoclase	9·45	
Albite	30·39	
Anorthite	27·80	
Diopside	4·70	23·55
Hypersthene	12·63	
Magnetite	3·94	
Ilmenite	2·28	
Water	1·16	
	99·95	

Class II	Dosalane
Order 5	Germanare
Rang 3	Andase
Subrang 4	Andose

The analysis is in no way exceptional, though its relation to that of the associated basalt is somewhat remarkable. The andesite contains more magnesia than the basalt analysed, and less soda and potash. The latter rock is clearly an alkaline type of basalt, and the association with it of nephelinite and alkaline-trachytes is by no means abnormal. The andesite, however, stands alone, and is no doubt the representative of a totally different series, of which it is as yet the only known member in this part of Portuguese West Africa.

Mineralogically similar andesites (also with alkaline associates) occur on São Thomé, in the Tristan da Cunha group, and near the Monapo River in Mozambique. In the table below, analyses of two other East African andesites are quoted for comparison, and though there is no detailed chemical or mineralogical resemblance, the fact of their occurrence is interesting, for like the Angola example and the rocks mentioned above, they are associated in the field with alkaline types of lavas. For close chemical analogues, it is necessary to compare rocks from western America and Kamchatka.

	A.	B.	C.	D.	E.	F.
SiO_2	56·14	60·76	56·65	56·91	56·47	57·32
Al_2O_3	17·81	16·81	22·11	18·18	15·33	19·79
Fe_2O_3	2·69	2·07	3·31	4·65	2·54	5·33
FeO	4·67	2·34	—	3·61	4·53	1·52
MgO	4·15	3·27	3·42	3·49	5·08	3·48
CaO	6·81	6·57	6·67	7·11	6·93	6·82
Na_2O	3·59	3·32	1·86	4·02	3·81	3·51
K_2O	1·63	2·10	4·10	1·61	1·66	1·62
H_2O	1·16	1·67	2·20	0·36	1·65	0·56
TiO_2	1·23	0·31	—	—	0·99	—
MnO	0·08	0·22	0·16	—	0·18	trace
P_2O_5	0·12	—	trace	0·25	0·54	—
Incl.	0·05	—	—	—	—	—
	100·13	99·44	100·48	100·19	99·71	99·95

A. Pyroxene-andesite, near Lucalla River, Angola. (Analyst, Harwood.)
B. Hornblende-andesite, near Monapo River, Mozambique. (Analyst, Holmes.)
C. Amphibole-biotite-andesite, Mt. Meru, East Africa. (Analyst, Pinkert.)
D. Pyroxene-andesite, Purgatorio, Pasto Volcano, Colombia. (Analyst, Kuch.)
E. Pyroxene-andesite, Munraven Peak, Yellowstone Park. (Analyst, Gooch.)
F. Augite-andesite, Korjaka, Kamchatka.

VI. General Discussion.

Perhaps the most interesting problem suggested by the assemblage of rocks described above is that of the relation of the pyroxene-andesite to the associated alkaline suite of lavas. The analyses, and the mineralogical

compositions of the rocks indicate clearly that the andesite could not have been produced by differentiation in the direct line of descent from olivine-basalt to alkali-trachyte. Such an intermediate rock, had it been erupted, should be a trachydolerite or a trachyandesite.[1] The close field association of calc-alkaline and alkaline types is admirably illustrated in eastern Africa (e.g. in Somaliland, Abyssinia, Kordofan, and the islands of Lake Rudolf; along the Uganda Railway and in the Kavirondo country; in the neighbourhood of Mount Meru and Kilima Njaro; along the Songwe River, and in Mozambique). In every case where the relations have been established, it is found that the eruption of the calc-alkaline series preceded that of the alkaline series, and that the andesites belonging to the former series are associated with basalts heavily charged with an excess of silica.[2] On the other hand, the basalts associated with the alkaline lavas are undersaturated[3] in silica.

In Angola, basalts of the oversaturated type have not yet been found. Specimen 545 of Monterio's collection carries a small amount of vesicular opal, but this does not constitute oversaturation, for the rock, like No. 548, contains unaltered phenocrysts of olivine. The andesite is therefore left without a recognized parent and without natural associates of any kind.

It is to be remembered, however, that the lavas from near the Lucalla River may not all be of the same age. By analogy with their neighbours, the rocks of the alkali series are probably of Tertiary age. The andesite may be of similar age or it may be late Karroo, and if the latter it would naturally fall into line with the wide-spread late Karroo basalt-andesite-rhyolite series of South and Central Africa. In this connexion, it is interesting to notice that rhyolites of a distinctly sub-alkaline type occur near Cuma where they were discovered by Professor J. W. Gregory during his recent journey through Benguella. In Benguella (near Chieuca and Ochilesa) the igneous rocks subsequently erupted were alkaline types[4] including nepheline-sodalite-syenite, shonkinite, ouachitite, and sölvsbergite. The basalts and dolerites occurring elsewhere in the same district were probably of the same or later age. The Benguella sequence—calc-alkaline succeeded by alkaline—thus conforms to that followed in many localities of eastern Africa. Whether this is also the

[1] See H. S. Washington, Journ. Geol., 1897, vol. v, p. 366.
[2] A. Holmes, Abstr. Proc. Geol. Soc., 1916, No. 994, p. 72.
[3] S. J. Shand, Geol. Mag., 1913, p. 508; 1914, p. 485; 1915, p. 339.
[4] G. W. Tyrrell, Trans. Roy. Soc. Edinburgh, 1916, vol. li, p. 550.

Rocks Characterized by :		Between Senza do Itombe and Bango [1]	Near Lucalla River, 30 miles N. of Cambambe [3]	Near Chieuca and Ochilesa.[4]	Near Dombe Grande.[5]	Between Cachanga and Cantiates.[6]
Alkali-Felspars	L.		Biotite-trachyte Aegirine-trachyte*	Sölvsbergite Akerite		Alkali-syenite
	M.			Shonkinite*		
Alkali-Felspars and Felspathoids	L.	Nepheline-phonolite Nepheline-syenite Nepheline-sodalite-syenite[2]		Tinguaite-vitrophyre Nepheline-sodalite-syenite Sodalite-syenite		
	M.	Olivine-ulrichite				
Calc-alkali-felspars and Felspathoids M.			Olivine-basalt * with Analcime		Basanite	
Felspar absent or accessory M.		Nepheline-monchiquite *	Nephelinite (Jacupirangite and Ijolite)	Ouachitite		
L = Leucocratic M = Mesocratic or Melanocratic			Associated with Olivine-basalt		Associated with Olivine-basalt	Associated with Gabbro

[1] A. Holmes, Geol. Mag., 1915, dec. 6, vol. ii, p. 369. [2] G. Berg, Min. Petr. Mitt., 1903, vol. xxii, p. 357. [3] This paper.
[4] G. W. Tyrrell, Trans. Roy. Soc. Edinburgh, 1916, vol. li, p. 550. [5] This paper. [6] P. da Sousa, C.R. Acad. Sci. Paris, 1916, vol. clxii, p. 692.

case farther north, in the Lucalla River area, can only be disclosed by future field work.

Alkaline rocks of late geological age are now known from several eruptive centres in Angola, and while there are distinct signs of consanguinity connecting them all, it is a curious fact that with one exception no individual type is represented at more than one locality. In the accompanying table the various assemblages are summarized (p. 72).

VII. Note on a Basanite from Dombe Grande, near Benguella. (Plate V, fig. 6.)

As already stated, this rock was collected by L. Malheiro, and was determined by J. P. Gomes as a nepheline-basalt. Since, however, the rock contains numerous laths of bytownite, it is here described as a basanite. The hand-specimen is at first glance barely distinguishable from that of the nephelinite described in § III. It is, however, more finely grained than that rock and is sprinkled not with pyroxene phenocrysts, but with serpentinized olivine and grains of iron-ore. Unlike the nephelinite, the basanite carries a few small amygdales occupied mainly by iron-stained analcime. Specific gravity 2·87.

The minerals identified under the microscope are as follows:

Small Phenocrysts.	Groundmass.
Pseudomorphs after Olivine.	Bytownite.
Titaniferous magnetite.	Nepheline and Analcime.
Apatite.	Grey-green and purple augite.
Bytownite (rare).	Aegirine-augite.
Amygdales.	Barkevikite.
Chlorite (lining).	Apatite and Iron-ores.
Analcime.	Calcite.
Calcite.	

Among the phenocrysts, olivine pseudomorphs are the most abundant. None of the original mineral now remains, alteration to red or reddish-brown iddingsite—sometimes with a core of leek-green serpentine—having been complete. Rectangular sections of titaniferous magnetite are sprinkled plentifully through the slide, in company with others of less regular outline. The presence of titanium is revealed by frequent alteration to leucoxene. Next in order of abundance come well-formed crystals of blue and smoky apatite, the haüyne-like appearance being due

(as in the nephelinite of the Lucalla River district) to the presence of innumerable gas pores drawn out parallel to the long axis. Small clear rods of apatite occur as inclusions in some of the titaniferous magnetite crystals, and the latter in turn are found in the olivine pseudomorphs. Bytownite in rectangular sections with broad twin-lamellae occurs sparingly. All the preceding constituents of the rock occur in it as inclusions, and the order of crystallization among the phenocrysts is thus clearly established.

In the groundmass, olivine is not represented. Laths of bytownite; hexagonal rods of apatite, some blue and smoky, some zoned, and others perfectly clear; grains of augite varying in colour from purple through brown and grey-green to the light green of aegirine-augite; shreds of barkevikite; and innumerable small rectangles of iron-ore, are distributed in a base of iron-stained analcime and nepheline. Analcime is sometimes present in approximately circular spaces with occasional sharp angles controlled by the disposition of dark minerals around the periphery. Among the latter, short wisps of reddish-brown barkevikite are generally present. Occasional traces of cubic cleavage, and a refractive index between 1·481 (castor oil) and 1·491 (toluol), together with the isotropic character, determine the identity of the mineral. Much of the colourless base of the groundmass has exactly the same appearance as the mineral of the open spaces, and there is therefore no reason to regard it as glass rather than analcime. In places blebs and patches of granular calcite are associated with the interstitial analcime. The same pair of minerals occupies the tiny amygdales of the rock, which are lined by a minutely banded variety of chlorite. Here and there the base contains plates of clear glassy nepheline, distinguishable from the neighbouring analcime by its superior refractive index, low double refraction, and uniaxial character. The mineral forms vaguely outlined plates in which the heavier minerals of the groundmass are poikilitically included.

The general order of crystallization for the various stages of consolidation may be stated as follows:—

Phenocrysts:

Apatite, titaniferous magnetite, olivine, bytownite.

Groundmass:

Apatite, titaniferous magnetite, bytownite, augite, aegirine-augite, barkevikite, nepheline, analcime (and calcite?).

Amygdales:

Chlorite, analcime, calcite.

Explanation of Plate V.

Figs. 1–5.—Near the Lucalla River, 30 miles north of Cambambe, Angola.

Fig. 1.—*Porphyritic Basalt* (No. 548). Ordinary light (× 18). Phenocrysts of labradorite and purple augite in a base of labradorite, pyroxenes, and iron-ores.

Fig. 2.—*Pyroxene-Andesite* (No. 544). Ordinary light (× 18). Phenocrysts of andesine and hypersthene in a groundmass of andesite laths, granular augite, and interstitial glass.

Fig. 3.—*Nephelinite* (No. 546). Ordinary light (× 30). Phenocrysts of nepheline, pyroxenes, sphene, and iron-ores, in a base of nepheline, analcime, and orthoclase.

Fig. 4.—*Jacupirangite.* Ordinary light (× 25). Cognate xenolith of melanocratic type in nephelinite (No. 546). Pyroxenes and iron-ores, with interstitial nepheline.

Fig. 5.—*Aegirine-Trachyte* (No. 559). Ordinary light (× 18). Phenocrysts of sanidine and aegirine in a trachytic groundmass of anorthoclase laths, soda-pyroxenes and amphiboles, and iron-ores.

Fig. 6.—*Basanite, Dombe Grande, near Benguella.* Ordinary light (× 25). Phenocrysts of olivine (altered to iddingsite and serpentine) and titaniferous magnetite, in a groundmass of bytownite, apatite, pyroxenes, barkevikite, nepheline, and analcime.

The photomicrographs are the work of Mr. G. S. Sweeting (of the Geological Dept., Imperial College), to whom I owe my thanks for the care with which he has prepared them.

Spencerite, a new Zinc Phosphate from British Columbia.[1]

By T. L. Walker, M.A., Ph.D., F.G.S.

Professor of Mineralogy, University of Toronto; Director of the Royal Ontario Museum of Mineralogy.

[Read June 20, 1916.]

THE mineral described in this paper occurs at the Hudson Bay zinc mine about five miles east of Salmo, near Nelson in the West Kootenay district of British Columbia. I regret that I have no data as to the exact character of the ore-body except that it occurs in a region where palaeozoic rocks are intruded by biotite-granite and that it is probably genetically connected with the intrusion of the latter. The zinc occurs in the form of the silicate and to a less extent the carbonate. There is also a small amount of oxidized lead-ore, principally cerussite. The main mass of the ore as shipped consists of these minerals mingled with soft friable limonite. In 1915 four thousand tons of ore, said to carry thirty per cent. of zinc, were shipped from this mine to smelters in the United States.

The silicate (hemimorphite), which is the chief economic mineral, forms banded mamillary masses or is a participant in building stalactitic structures. Only rarely is it crystallized, and it then occurs in cavities in the limonite either as small, fan-shaped structures or as radiating clusters of small, clear crystals which are too small for satisfactory goniometric examination.

The mineral here described forms the central portion of these stalactitic growths, being surrounded by a shell of hemimorphite. Sometimes as

[1] An abstract of this paper appeared in 'Nature', June 29, 1916, vol. xcvii, p. 375, and Geol. Mag., July 1916, vol. iii, p. 336. In the meantime the same mineral, from the same locality and under the name spencerite, has been briefly described by A. H. Phillips, Amer. Journ. Sci., September 1916, ser. 4, vol. xlii, p. 275. The results of his analysis confirm the chemical formula given below.

a result of solution of the outer zone of the spencerite there is formed, between the silicate and the core of spencerite, an open space into which exceedingly delicate plates of hemimorphite project from the outer wall. This has apparently been brought about by the solution of the outer part of the spencerite, the thin plates of hemimorphite having been included in the spencerite along cleavage-planes before the solution occurred. This type of silicate is spherulitic in structure and is found occasionally in the spencerite in minute, flat plates following the best cleavage. It is readily recognized when the mineral is examined between crossed nicols by the presence of a black cross for each spherulitic individual.

Chemical Properties.

The mineral dissolves very readily in acids. On adding ammonia to the acid solution a heavy white precipitate forms and dissolves in excess of the reagent. In this respect spencerite resembles the phosphates of zinc previously described. The quantitative analysis shows that the mineral is exceedingly pure and that it agrees very closely with the formula $Zn_3(PO_4)_2 \cdot Zn(OH)_2 \cdot 3\,H_2O$, the calculated percentage composition of which is given in column IV. Two analyses were made by the writer (I and II) and a third by Mr. E. W. Widdowson, of Nelson, B. C. (III).

	I.	II.	III.	IV.
ZnO ...	60·18	60·18	60·05	60·32
P_2O_5 ...	26·14	26·23	26·74	26·32
Water at 160° ...	9·79	9·83	13·70	10·02
Water above 200° ...	3·53	3·47		3·34
MnO ...	—	—	0·41	—
Silica ...	—	—	0·40	—
	99·64	99·71	101·30	100·00

When heated in a closed tube the mineral decrepitates and yields water in abundance. While hot the material is yellow, becoming white again on cooling; thus indicating the presence of a basic salt of zinc. The temperatures at which the water is given off are indicated in the above analyses. Between 160° C. and 200° C. there is no loss. At 400° C. the whole of the water is set free except 0·21 per cent., which appears to be still more firmly held and is set free only at a somewhat higher temperature. This difference in the attachment of the water

corresponds with the formula suggested above, in which one-fourth of the water is combined to form zinc hydroxide, while the other three-fourths may be regarded as water of crystallization.

Physical Properties.

The density of the mineral was determined as 3·145 by means of the hydrostatic balance and as 3·142 by the use of heavy solutions. The mineral is about 3 in the scale of hardness. When the powder is heated to a moderate red-heat the mineral fuses readily. It is pure white in colour. The lustre is usually pearly but occasionally vitreous. The cleavages are in three directions and of different degrees of perfection, one of them being very perfect, while the other two are slightly less so. The best cleavage lends to the mineral a somewhat scaly structure. If a small fragment be broken up and examined with a low power under the microscope it is seen that almost all the pieces lie with the best cleavage parallel to the glass support. The other cleavages as observed on these fragments appear to be at right angles to one another, so that the mineral seems to be in agreement with the rhombic system. That the plates are almost all of a common crystallographic orientation is shown by the fact that they show, when examined in convergent light, a biaxial interference-figure. Such cleavage-plates can be also readily distinguished from the small number following one of the other cleavages, because the former exhibit very low birefringence as compared with the latter.

Optical Properties.

The mineral is too cleavable to make it possible to cut prisms to determine the indices of refraction. An attempt was made to find these constants by total reflection, using thin plates parallel to the best cleavage. Since these plates give good interference-figures, the acute bisectrix is apparently normal to this cleavage. Owing to the smallness of the cleavage-plates and slight lack of parallelism of different parts of a single plate the results were very unsatisfactory. The value for β for sodium-light is about 1·6092. The optic angle for sodium-light was measured on the axial angle apparatus of Fuess, using monobromonaphthalene instead of oil: $2H_y = 46° 26'$, hence $2E_y = 81° 34'$ and $2V_y = 47° 54'$.

The mineral as shown by examination of the interference-figure is negative, the optic normal being at right angles to the trace of the

poorest of the three cleavages and the obtuse bisectrix at right angles to the trace of the second best cleavage. Plates parallel to the best cleavage show low birefringence, so that the difference between β and γ is not great. Such plates when examined between crossed nicols exhibit peculiar interference-colours, which suggest that the plates are not

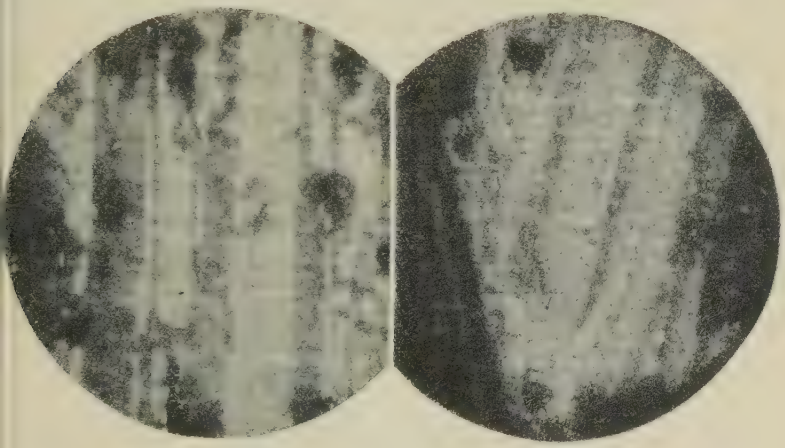


FIG. 1. FIG. 2.

Micro-sections of Spencerite showing lamellar twinning.

simple, but rather are composed of several very thin plates arranged so that there is a lack of parallelism. Dispersion $\rho > v$.

Crystallization.

In general, the optical and physical properties above mentioned seem to suggest that the mineral is rhombic in crystallization. This is not the case however, as shown by the following:

(*a*) A thin section cut more or less at right angles to the best cleavage shows that the mineral is polysynthetically twinned with an extinction-angle of about 6°. The plates of the twin complex are parallel to the best cleavage. (Figs. 1 and 2.)

(*b*) By etching with cold, one per cent. nitric acid for five minutes, very definite etch-figures are obtained on the best cleavage. These figures are symmetrical about only one plane (the second best cleavage), and consequently the best cleavage does not correspond to a pinakoidal cleavage in a holohedral

rhombic crystal, but rather to that of a face in the orthodiagonal zone of a monoclinic crystal such as (100) or (001). (Fig. 3 shown on (100).)

It is therefore the opinion of the writer that the mineral may be regarded as monoclinic. If we assume that the best cleavage be (100), the second cleavage (010), and the poorest cleavage (001), then the twinning-plane and composition-face is (100), and the optic axial plane lies in the orthodiagonal zone and nearly normal to the front pinakoid. In this case the optic angles measured are only approximate, being produced from a series of thin twinned plates parallel to (100), each of which, if taken apart from the others would show an angle differing slightly from

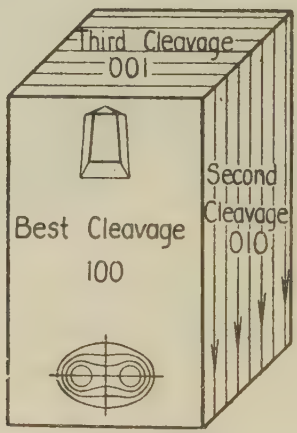


Fig. 3.—Crystallographic scheme of Spencerite.

that obtained on the composite plates. In the same way the value for β is not the true value.

The writer has examined carefully the specimens from the Hudson Bay mine for crystals of this new mineral, but without success. The stalactitic masses, which up to the present are the only form in which it has been observed, are always covered by solution surfaces, a zone between it and the covering silicate having been dissolved away. While from the optical properties the mineral appears to be monoclinic, it would be interesting to confirm this conclusion by direct geometrical measurement of crystals. In fig. 3 the chief crystallographic observations are diagrammatically represented.

General Relationships.

Spencerite is most closely related to hopeite, parahopeite, and tarbuttite, as shown by the following table:

Hopeite	...	$Zn_3(PO_4)_2 \cdot 4\,H_2O$
Parahopeite	...	$Zn_3(PO_4)_2 \cdot 4\,H_2O$
Tarbuttite	...	$Zn_3(PO_4)_2 \cdot Zn(OH)_2$
Spencerite	...	$Zn_3(PO_4)_2 \cdot Zn(OH)_2 \cdot 3\,H_2O$

This new mineral may be regarded as the trihydrate of tarbuttite. Prior to 1907 hopeite was the only representative of this series, and this had been found very sparingly at only one locality. Subsequently it was found in some abundance, together with the new species parahopeite and tarbuttite, at Broken Hill in North-Western Rhodesia. The name suggested for this mineral is given in honour of Mr. L. J. Spencer, of the Mineral Department of the British Museum (Natural History), who is responsible for much of our knowledge of the natural zinc phosphates.

University of Toronto,
May 1, 1916.

A butterfly-twin of Gypsum.[1]

By L. J. Spencer, M.A., F.G.S.

Assistant in the Mineral Department of the British Museum.

[Read March 21, 1916.]

THE specimen[2] here described was acquired in 1913 for the mineral collection of the British Museum. It came from one of the numerous sulphur mines in the province of Girgenti, Sicily. Being of some size (15 cm. = 6 inches across) and with the two individuals well separated and symmetrically disposed, it affords a striking illustration of a twin growth. The crystal is colourless and perfectly transparent; it encloses one or two small patches of native sulphur and compact limestone. A portion, probably about one-third, of the original specimen has been broken away along the perfect cleavage of gypsum; and this fact, together with the small point of attachment, increases the resemblance of the twin to the butterfly form, which is here more striking than in the so-called butterfly-twins of calcite.

The habit of the individual crystals is tabular and lenticular, there being a large curved surface approximating in position to the plane *e* (10$\bar{3}$), which lies 11° 29′ behind the basal plane *c* (001) in gypsum. The faces *b* (010) and *m* (110) in the prism-zone are quite narrow, and these are the only surfaces on the crystal that are really plane. Between the rounded surface *e* and the faces *b*, *m*, and *m*′, and lying in these zones, there are other rounded surfaces with approximately the positions w_1 (1$\bar{2}$3), y_1 (123), and x_1 (2$\bar{1}$3). Rough measurements with the contact goniometer gave the angles: $ew_1 = 13$–$17°$, $ey_1 = 20$–$27°$, and $ex_1 = 12$–$15°$. Like the surface *e*, these are also prominently marked with rounded hillocks, ridges, and grooves of growth. A single, simple crystal developed on all sides would thus present the form of a six-sided lenticle, somewhat resembling the flat crystals of mimetite from Johanngeorgenstadt, Saxony.

[1] Communicated by permission of the Trustees of the British Museum.

[2] Regd. No. B. M. 1913, 339.

Fig. 1 reproduces a photograph, kindly taken by Mr. T. Crook, of the specimen, in which the butterfly form is well shown. Fig. 2 shows, more or less diagrammatically, the cleavage surface *b* (010), which is continuous through the two individuals. Here are indicated the fibrous cleavage (by double lines) parallel to *n* (111), the conchoidal cleavage

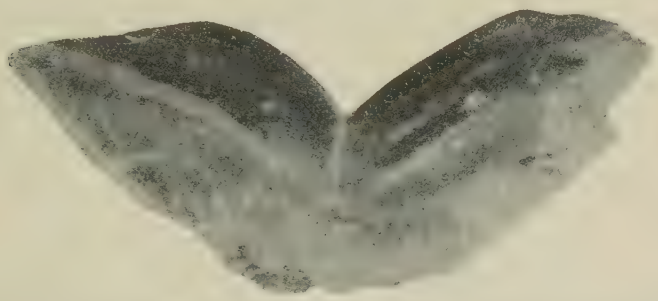


Fig. 1.—**Photographic reproduction of a twinned crystal of Gypsum from Girgenti, Sicily.**

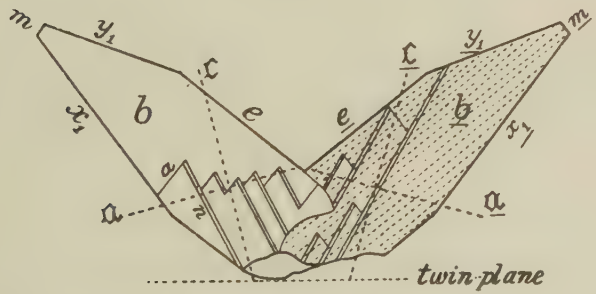


Fig. 2.—**Diagrammatic sketch on the plane of symmetry of a crystal of Gypsum twinned on *d* (101).**

parallel to *a* (100), and (by dotted lines) the directions of optical extinction. The re-entrant angle formed by the two *e* planes was measured from the tracing of the *b* cleavage (fig. 2) as 102°, the calculated[1] angle for twin-plane *d* (101) being $e\,\underline{e} = 100° 28'$. The angle between the traces on *b* of the *n* cleavage in the two portions was found to be 57° (calculated $\underline{t} = 57° 9'$), and that formed by the *a* cleavages 74° (calculated $a\,\underline{a}$ 74° 9').

[1] Calculated from Des Cloizeaux's angles as quoted by Dana, 'System of Mineralogy,' 6th edition, 1892.

The minimum angle between the directions of optical extinction in the two portions was measured in a flake detached from the specimen as 30° (calculated $c\,\underline{c}=30°$).

The law of twinning is therefore the common one in which *d* (101) is the twin-plane, but with this difference: whereas in the usual type of twin the two individuals are situated on opposite sides of the twin-plane, here they both lie on the same side of this plane. The former case gives the well-known 'swallow-tail' or Paris twin of gypsum; and another form of the same, but remarkable in showing no re-entrant angles, has recently been figured in this magazine.[1] The latter case does not appear to have been previously described for gypsum, except in the intercrossing twins (fig. 4) according to this law.

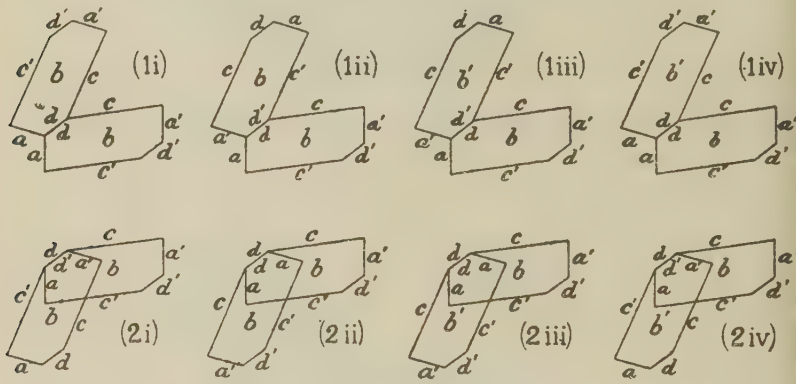


Fig. 3.—The several methods possible of twinning Gypsum on the plane *d* (101).

The diagrams in fig. 3 illustrate the several ways by which one portion of this twin may be brought into a position coincident with the other portion.

Type 1 (in which the two individuals are situated on opposite sides of the twin-plane) :—

(1 i). By reflection (symmetrical repetition) across the twin-plane *d* (101).

(1 ii). By reflection across a plane perpendicular to *d*, and a parallel shift across the twin-plane (i.e. a parallel shift from the position given in (2 ii).

[1] M. Fletcher, 'Note on some artificially-produced crystals of Gypsum.' Mineralogical Magazine, 1911, vol. xvi, pp. 137–139.

(1 iii). By a rotation of 180° about an axis (twin-axis) normal to the twin-plane *d*, and a parallel shift across the twin-plane.

(1 iv). By a rotation of 180° about an axis parallel to the edge *db* (i.e. a zone-axis lying in the twin-plane and normal to the twin-axis).

Type 2 (in which the two individuals are situated on the same side of the twin-plane) :—

(2 i). By reflection across the twin-plane *d*, and a parallel shift across this plane.

(2 ii). By reflection across a plane perpendicular to *d*.

(2 iii). By a rotation of 180° about an axis normal to the plane *d*.

(2 iv). By a rotation of 180° about an axis parallel to the edge *db*, and a parallel shift across the twin-plane.

Each of the positions in either one of these types is obtained from the corresponding position of the other type by a parallel shift across the twin-plane; and the re-entrant angle in one type is the supplement of that in the other type. These operations are readily followed by using a piece of card lettered on the two sides.

In a holosymmetric monoclinic crystal like gypsum the four positions in each of the two types are of course identical, although they have been obtained by different operations. There would, however, be distinctions if the crystal belonged to the hemihedral or hemimorphic classes of this system.

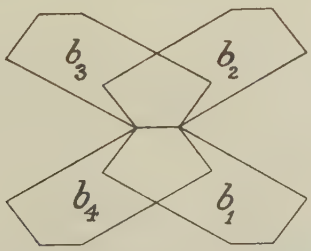


Fig. 4.—Intercrossing *d*-twin of Gypsum.

A combination of the two types gives the intercrossing *d*-twin of gypsum shown in fig. 4. Here the diagonally opposed portions are in parallel position, being related to one another by the parallel shift across

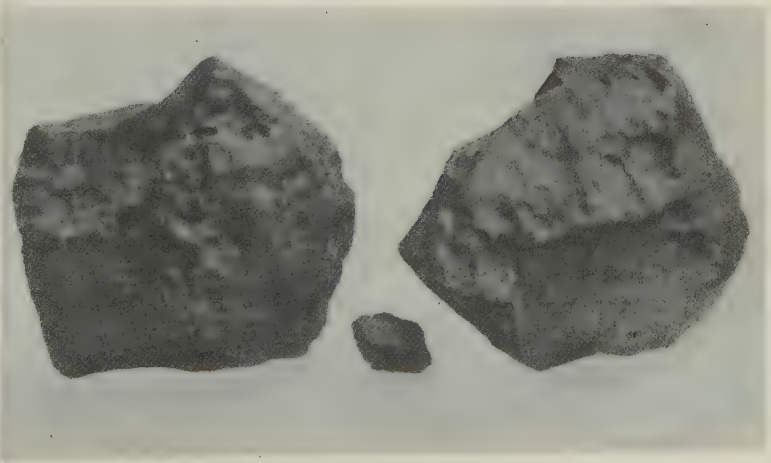
the twin-plane. Examples of this type have been described by F. Hessenberg[1] in 1872 and by A. Lacroix[2] in 1907.

Twins of the first type are usually described by stating that *d* (101) is the twin-plane and combination-plane; and those of the second type as having twin-plane *d* and combination-plane perpendicular to the twin-plane, i.e. parallel to the twin-axis. In the specimen here described the junction between the two individuals is clearly seen (fig. 2); it is not perpendicular to the twin-plane, but runs in an irregular direction. The difference between the two types would be better described by stating that the two individuals are situated on opposite sides of the twin-plane (as in type 1), or both on the same side of the twin-plane (as in type 2).

[1] F. Hessenberg, 'Mineralogische Notizen,' Abhandl. Senckenb. Naturf. Ges., 1872, vol. viii, p. 35, plate 2, figs. 22 and 25.

[2] A. Lacroix, 'Le Gypse de Paris . . .', Nouv. Arch. Muséum Hist. Nat. Paris, 1907, ser. 3, vol. ix, p. 214; 'Minéralogie de la France,' 1910, vol. iv, p. 182.

Fig. 1.



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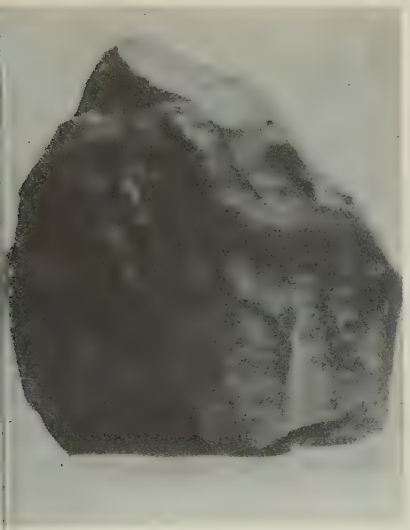

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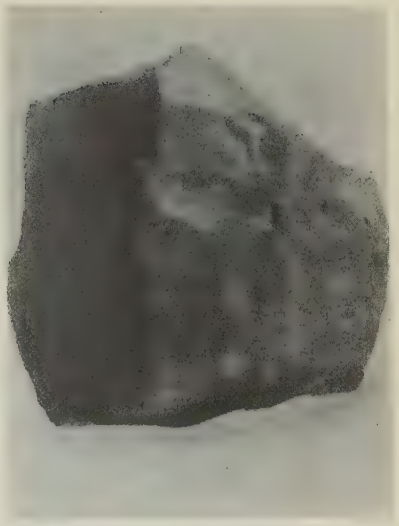


Fig. 2.

Fig. 3.

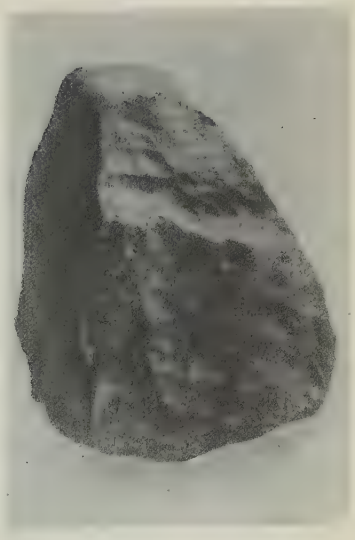


Fig. 4.

G. T. Prior: Meteoric Stones of Warbreccan, Queensland.

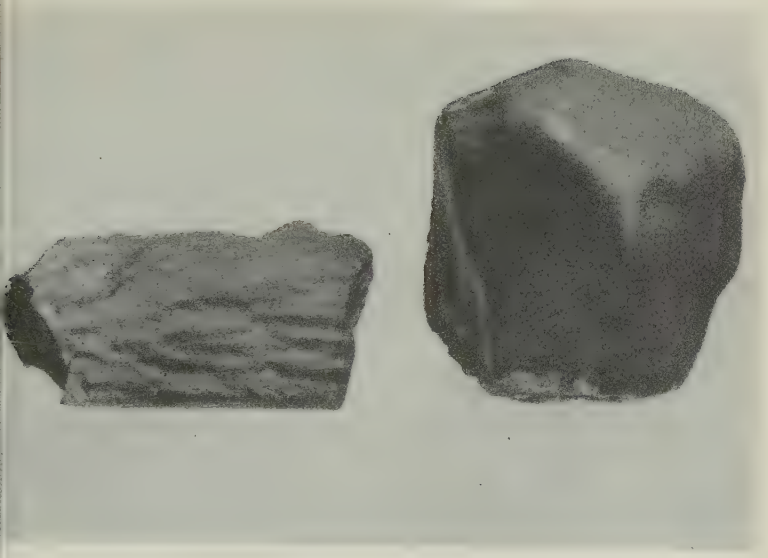


Fig. 1. Fig. 2.

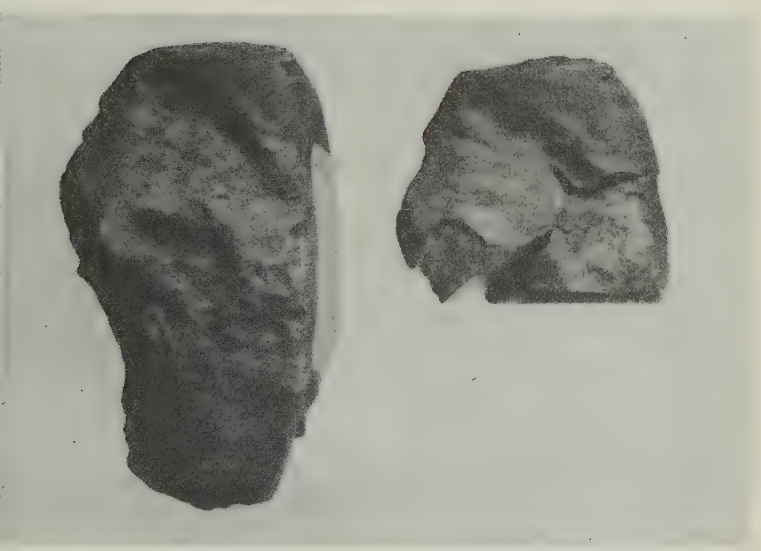


Fig. 3. Fig. 4.

T. Prior: Meteoric Stones of Cronstad and Daniel's Kuil.

Fig. 1.

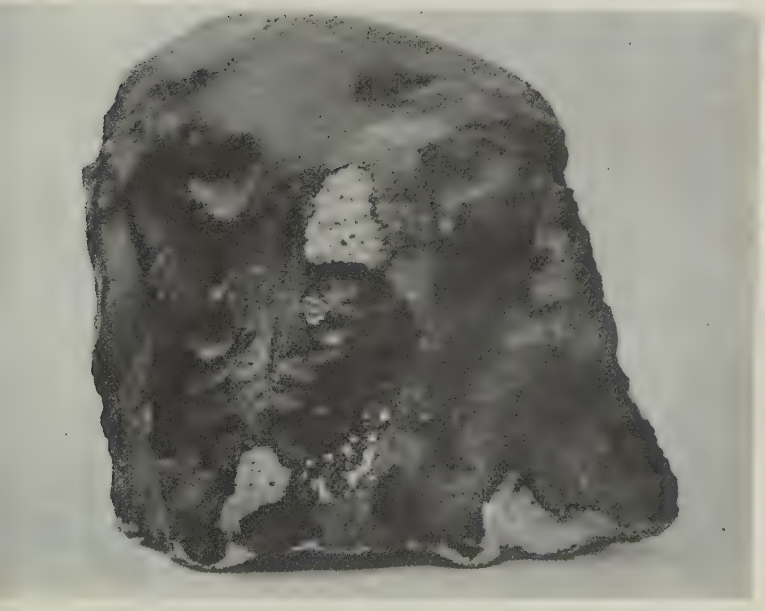
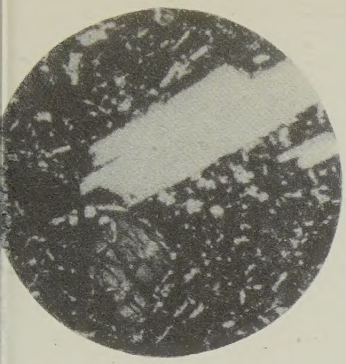


Fig. 2.



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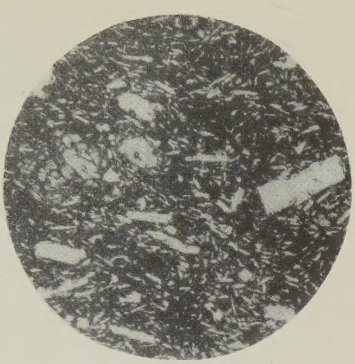

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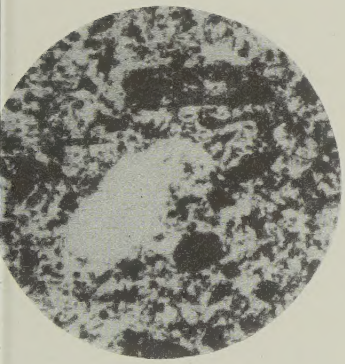

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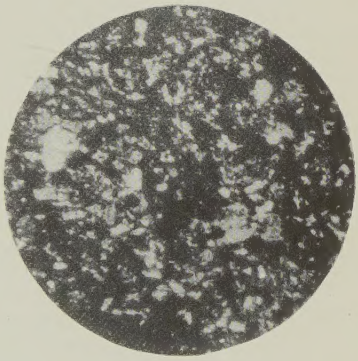

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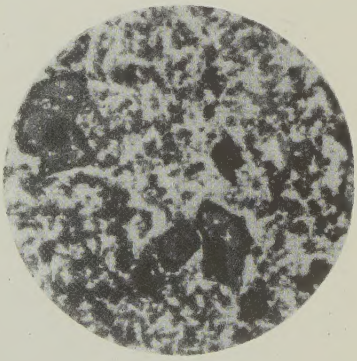

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A. Holmes: Volcanic Rocks from Angola.